S100 18

THE OPEN UNIVERSITY

Science Foundation Course Unit 18

# Cells and organisms

The Open University

*Science Foundation Course Unit 18*

# CELLS AND ORGANISMS

*Prepared by the Science Foundation Course Team*

THE OPEN UNIVERSITY PRESS

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The Open University Press
Walton Hall, Bletchley, Bucks

First Published 1971


Designed by The Media Development Group of the Open University

Printed in Great Britain by
Oxley Press Ltd,
London and Edinburgh

SBN 335 02009 7

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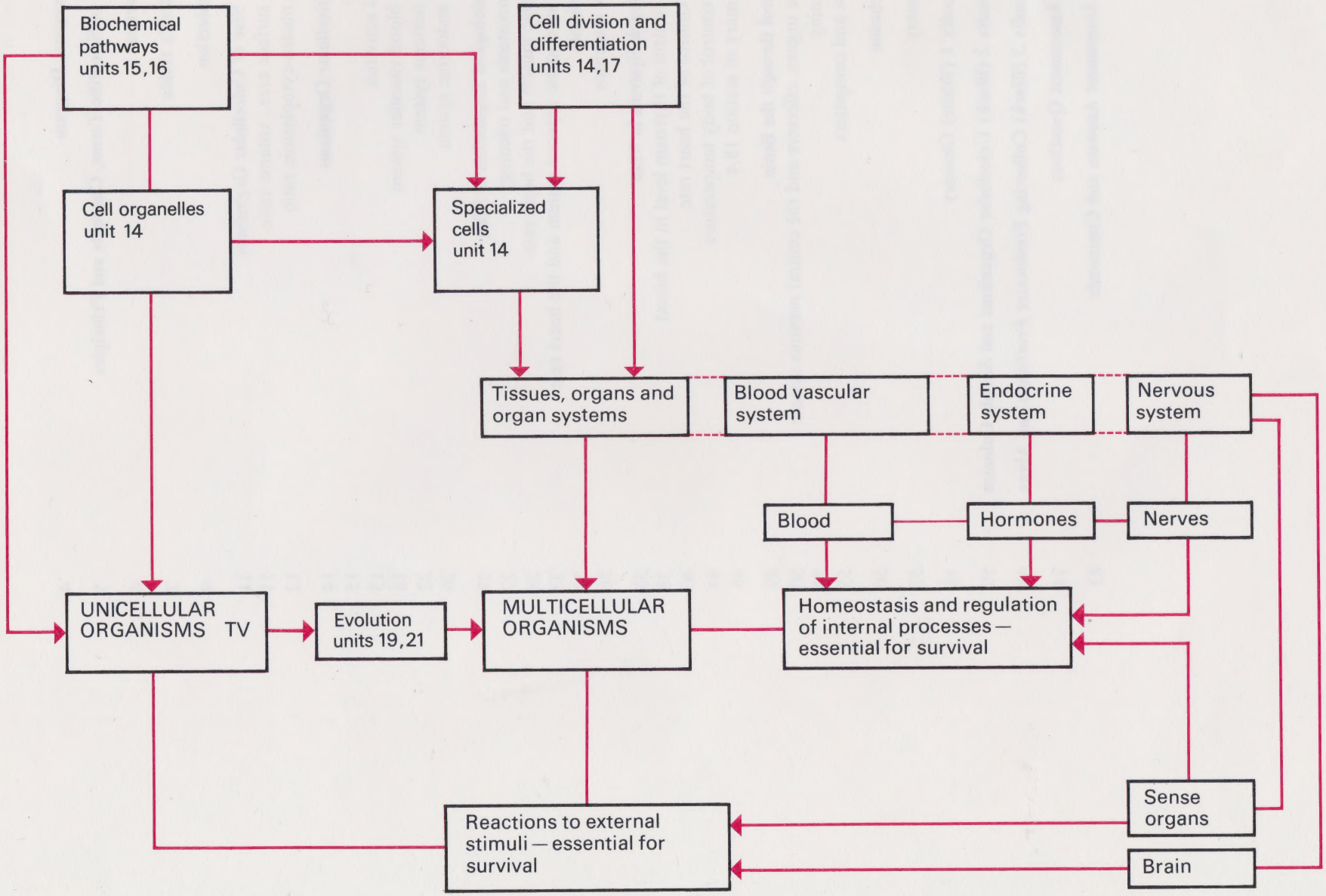

Table A

## List of Scientific Terms, Concepts and Principles used in Unit 18*

| Taken as pre-requisites | | | Introduced in this Unit | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | | 3 | | 4 | |
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| | | | neurosecretory cells | 39 | | |
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| | | | cilia | TV | | |

* *Any scientific terms used in this Unit but not listed are marked thus † and defined in the glossary.*

## Objectives

When you have finished your study of this Unit, you should be able to:

1 Define correctly, or recognize the best definitions of, or distinguish between true and false statements concerning each of the concepts and principles listed in column 3 of Table A. (*SAQs* 1, 3, 4, 5, 6, 10, 11, 14, 20)

2 Select at least two features of the blood vascular system, endocrine system and nervous system from a given list of statements. (*SAQ* 5)

3 Given relevant data, predict or interpret the effects of changing the components of physiological feedback systems. (*SAQs* 13, 19)

4 Given appropriate information, recognize kymograph records or electrocardiograms showing the effects of various substances on the heart rate. (*SAQs* 7, 8)

5 Given appropriate information, interpret or draw flow diagrams or feedback diagrams to illustrate how physiological systems function, *or* put arrows between boxes to construct such diagrams. (*SAQs* 12, 15, 20)

6 Distinguish between teleological and non-teleological statements. (*SAQ* 16)

7 State or recognize at least three differences between the endocrine and nervous systems as regards their functioning in control and regulation in the body. (*SAQ* 10)

8 Use the principles given in this Unit to make hypotheses or design experiments or draw conclusions from listed data not treated in the Unit. (*SAQs* 2, 7, 8, 9, 17, 18, 21)

## Student's Guide

So far, you have studied cells and cell components; you have learnt about their structure and their metabolism. In this Unit, you begin to study whole organisms and you will continue to do so through Units 19, 20 and 21. Most of the contents of the white text of this Unit fall within the field of human physiology†; this means that you should find everyday experiences relevant to some of the problems discussed.

The first section deals with the limitations imposed on organisms that consist of single cells. The Unit's TV programme will show you some of these organisms. Those of you with more time, or with a previous knowledge of biology, can read black-page Appendices 2 and 3 and learn more about unicellular organisms and simple colonies that live in fresh water. If you are interested, we hope that you will continue to collect and study these organisms whenever you have time to spare and not just during this week.

The rest of the Unit concerns problems of many-celled (multicellular) organisms, and man is taken as a convenient example. Section 18.2 is a brief account of human anatomy†, necessary for an appreciation of the physiological problems discussed later and their solutions. If you are unfamiliar with anatomical terms, you may find them difficult—but you are not expected to remember them or the details given in the text except for those listed under Objective 1 (Table A). Even those will not be required for the final examination.

In section 18.3, the necessity for co-ordination among the cells of a multicellular organism is related to the necessity for homeostasis, defined in 18.3.1. The three mechanisms responsible for co-ordination—cell to cell interaction, hormones, nervous systems—are explained, using the heart beat as the example of the physiological function regulated. You will see a demonstration of a rabbit's heart beat being recorded during the TV programme.

Control of physiological functions can be interpreted, using the engineer's concepts of flow diagrams and feedback systems. This is illustrated in section 18.4 by studying three examples. The first, control of secretion of the hormone thyroxin, is a simple system depending almost entirely on secretion of hormones. The other two, control of the heart beat and control of body temperature, are more complicated; they involve antagonistic effects between parts of the nervous system. If you are having difficulty, read sections 18.4.2 and 18.4.3 fast, without attempting the problems in the text.

The final section, 18.5, is concerned with responses to external stimuli, essential for the survival of an organism in a hostile world. Information theory, which you have met already in Units 16 and 17, is used to explain how the stimulation of sense organs can result in effective action through muscular responses. The role of the nervous system and especially of the brain is described. The importance of synapses, described earlier in sections 18.2.4 and 18.3.4, is stressed, with special reference to reflexes and to learning. The Unit's radio programme takes up a problem touched on in this last section—the similarities and differences between brains and computers.

The central theme of Unit 18 is that an organism reacts as a single whole to changes in the environment—to survive, it must maintain homeostasis internally and react effectively to external stimuli. How it achieves this is the province of physiology, and we give you here a few examples illustrating the principal mechanisms exhibited by large multicellular animals.

## 18.0 Introduction

Units 14 to 16 dealt with life at the cellular and sub-cellular level—you studied the organelles which are generally present in cells: the nucleus, mitochondria, chloroplasts, endoplasmic reticulum, ribosomes. You also studied some of the biochemical reactions which occur in cells and several ways in which energy is released or made available for further reactions. You met the concept of the regulation of different simultaneous processes in cells to give balanced equilibria and the concept of hierarchy in the organization of cell biochemistry. You also studied some specialized plant and animal cells. Some of these cells can be grown in cultures in the laboratory, where they are supplied with ideal conditions of chemical environment and temperature. You saw pictures of some single cells that lead an independent existence in natural environments, but the majority of cells, in fact, do not exist alone but only as part of a group of cells.

Living units which survive independently under natural conditions are called 'organisms'. Some of these organisms consist of single cells but many of them are multicellular with $10^2$ or $10^3$ up to $10^{16}$ cells in their bodies. However small or large the number of cells comprising it, the organism is able to perform all the physiological and biochemical functions that are characteristic of life. In the single-celled organism, all these functions are carried out within the single cell, but there are limitations to what a single-celled organism can achieve; we shall discuss some of these in section 18.1. These limitations can be overcome in a multicellular organism, where many of the functions are distributed among the cells, some of which are specialized both structurally and biochemically (Unit 14). Such specialized cells are usually grouped into 'tissues' and the tissues into 'organs' and the organs into 'organ systems'. This distribution of functions among the cells of the body is sometimes referred to as 'division of labour'. You may find it helpful to make a mental comparison between an organism consisting of many cells and a human community where many individuals work at different tasks but rely on each other to make the whole community 'self-supporting'. Every living cell within the organism must carry out for itself some of the biochemical processes described earlier—just as every person within the community must eat and drink and sleep.

**List some of the processes which you would expect to find occurring in all living cells.**

Fat and protein synthesis, energy-releasing sequences such as glycolysis and the Krebs cycle.

If a multicellular organism is to survive, there must be a balance between the numbers of cells performing different specialized functions so that the organism has a characteristic shape and structure of body (a characteristic anatomy) and there must be a balance between the different biochemical activities of the cells (a physiological† balance). Both must be related to the environmental conditions outside the organism.

We shall be especially concerned with the regulation of this physiological balance in sections 18.3 and 18.4 and with the co-ordination within the organism of its reactions to the outside world in sections 18.4 and 18.5, using man as an example of a multicellular organism. In section 18.2 we shall deal briefly with the anatomy of man, since you need to know some anatomy before you can appreciate the problems of physiological regulation and their solutions.

You are not expected to remember details, apart from these relevant to Objective 1.

**Recommended reading**

There is no prescribed reading for this Unit. You will find references in the text to parts of *The Chemistry of Life* that give more information about certain topics treated here. If you wish to read one of the recommended books, you will find that the following chapters are related to this Unit:

N. J. Berrill, *Biology in Action*. Heinemann, 1967 (Chapters 11, 13, 25 and 26).

S. D. Gerking, *Biological Systems*. Saunders, 1967 (Chapters 5, 11, 16 and 17).

P. B. Weisz, *et al.*, *The Science of Biology*. McGraw-Hill, 1967 (Chapters 2, 7, 12, 22, 23 and 25).

You will read about a greater diversity of animals in Unit 21. You could also read Buchsbaum, *Animals without backbones*, especially volume 1, and Romer, *Man and the Vertebrates*, especially volume 1.

## 18.1 The Size of Unicellular Organisms

All unicellular organisms are small. The largest common ones reach lengths of about 3 mm and many are just visible to the naked eye, but the great majority can be seen only with a microscope. There are two possible reasons why they do not attain a larger size. The first is the necessity to maintain a large area of surface membrane in relation to the volume. The second is the necessity to maintain a minimum volume of nuclear material in relation to the volume of cytoplasm.

### 18.1.1 The surface area: volume ratio

All the interactions between a cell and its environment occur at or through the cell surface and one constant feature of unicellular organisms is the presence of a cell membrane. You have studied some of the properties of this in earlier Units (14 to 16). All cells need to absorb some substances from their environment and to discharge others—the actual substances depend on the type of metabolism occurring in the cell.

The substances absorbed through the cell membrane are used in processes inside the cell and materials inside the cell must leave by passing through the surface membrane. Clearly the cell might produce so much material that the exit routes would become jammed and the material would accumulate inside the cell. Obviously it is also possible that cell metabolism might use up certain substances more quickly than fresh supplies could enter through the cell surface to replace the metabolized substances and, in consequence, activities within the cell might slow down or stop. So the relationship between area of cell surface and volume of cell contents can be critical.

surface area to volume ratio

**How does the surface area to volume ratio vary in cells of different sizes and shapes?**

**If you do not know the answer, carry out the following calculations.**

**1 Compare cubes with sides of 1, 2 and 3 cm by filling in the blanks in the following table:**

| *Length of side (L) cm* | *1* | *2* | *3* |
|---|---|---|---|
| *Surface area* ($6 \times L^2$) $cm^2$ | | | |
| *Volume* ($L^3$) $cm^3$ | | | |
| *Area : Volume ratio* | | | |

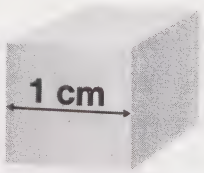
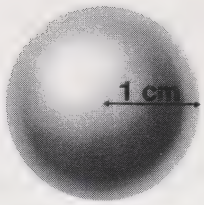



*Figure 1 (a) Cube with edges 1 cm long.*

**2 Compare spheres with radius of 1, 2 and 3 cm by filling in the blanks in the following:**

| *Radius (R) cm* | *1* | *2* | *3* |
|---|---|---|---|
| *Surface area* ($4\pi R^2$) $cm^2$ | $4\pi$ | $16\pi$ | $36\pi$ |
| *Volume* ($4/3\pi R^3$) $cm^3$ | $4/3\pi$ | $32/3\pi$ | $108/3\pi$ |
| *Area: Volume ratio* | 3:1 | 3:1 | 1:1 |




1 (*b*) *Sphere with radius* 1 *cm.*

*The filled-in tables are on p.* 15.

**The following generalizations can be drawn from the formulae used.**

**(a) The surface area is proportional to the square of the linear dimension (side length or radius).**

**(b) The volume is proportional to the cube of the linear dimension.**

*So* as the linear dimension increases, the area:volume ratio falls, i.e. small cells should have a greater surface area to volume ratio than large cells of the same shape.

Take a spherical ball of plasticene or any other easily deformed solid (e.g. bread) and mould it into various shapes.

**What shapes give large area: volume ratios?**

Flatten the ball into a disc and there is a great increase in surface area with no change in volume. Roll the ball into a long 'sausage' and again there is a great increase in surface area with no change in volume.

In fact a sphere has the least possible surface area for any given volume.

A few organisms are nearly spherical, but most unicells are either elongated or have complicated shapes with finger-like extensions sticking out. The cell surface area to volume ratio is thus higher than it would be for a sphere.

## 18.1.2 The nucleo-cytoplasmic ratio

You have learnt about the important part played by the nucleus in controlling the activities of the cell in Units 14 to 17.

Since the interaction between nucleus and cytoplasm takes place through the nuclear membrane, the size of the nucleus may well be limited by the ratio of nuclear membrane area to nuclear volume.

There appears to be an upper limit to the amount of cytoplasm which can be effectively controlled by a single nucleus. There are some organisms which have many nuclei within bodies which are not divided into separate cells. Some of these have unusual metabolic pathways. They all show very vigorous streaming movements of the cytoplasm; it is possible that these movements circulate chemical substances and thus lead to co-ordination of the activity of the nuclei. Some sort of co-ordination is necessary if the organism is to behave as a single unit.

There are large numbers of different sorts of unicellular organisms and they use a variety of metabolic pathways and show degrees of complexity

ranging from 'simple' to highly complex. Some will be shown in this Unit's TV programme, others are illustrated in film strips 18(a) and 18(b) and in Appendix 2 (Black). There is an upper limit to their size, which seldom exceeds a few millimetres in the longest dimension.

One of the characteristics of living cells is that they grow, given suitable conditions; but it should be clear that cells cannot simply continue to grow larger and larger since the surface area to volume ratio must impose a limit. One solution to this problem is for the growing cell to divide into two cells; if both of these grow, they can attain together a larger volume than the single cell since they have twice the surface area of a single cell.

**Turn back to your calculation about cubes. How many cubes with sides of 1 cm can have the same total volume as one cube with sides of 2 cm?**

Eight.

**What would be the total surface area of this number of cubes with sides of 1 cm? How does this area compare with the surface area of a cube with sides of 2 cm?**

Eight cubes would have a total surface area of 48 $cm^2$. This is twice the surface area of a single cube with the same volume.

If two or more cells are to be a single organism, then there must be some sort of communication system through which they co-ordinate their activities—if they do not do this, they will simply be two or more independent organisms. The necessity for co-ordination becomes more important as the number of cells in the organism increases.

## 18.2 Multicellular Organisms

All large organisms consist of many cells.

**What advantages do they gain by being larger than the unicellar organisms?**

Large organisms are more independent of the environment than are smaller ones.

If you watch unicellular organisms under the microscope—as in this Unit's TV programme—you gain the impression that some of them swim fast. *Paramoecium* for instance is 250 $\mu$m long and can maintain a speed of about 3 mm per second for two hours.

**How many times its own body length does the *Paramoecium* travel in one second?**

120 times.

**Compare this with a motor car—if a car that is 16 feet long travels at 60 miles per hour, how many times its own length does it travel in one second?**

5½ times.

**The motor car would cover 60 miles in one hour—how far would the *Paramoecium* travel in one hour?**

10.8 metres.

A small organism in water can make no headway against water movement due to wind or currents. This may not be a disadvantage: there are many microscopically small organisms in oceans and in lakes which spend their whole lives floating in the upper layers of water (see Appendix 2 (Black)). Animals with muscles can move much faster in water than unicellular organisms and they can also move on land.

Multicellular organisms range in size from some such as Rotifers (see film strip 18(b), 16), that are as small as *Paramoecium*, to the blue whale (the largest known animal, weighing up to 100 tonnes and up to 30 m long) and the giant redwood (the largest known plant, growing up to a height above ground of 100 m). You can read about the variety of animals if you wish, in the two books mentioned in section 18.0.

All these organisms are communities of cells that are organized to form characteristic structures through the processes of cell division and differentiation. In Unit 17 you learnt how the nucleus controls protein synthesis and, through this process, development. Thus the anatomy of an organism is the result of its genetic constitution, modified to some extent by direct effects of the environment. You will learn more about this in Unit 19.

In this Unit, we are concerned with co-ordination within the body of an adult organism of the activities of its component cells. The organism behaves as an integrated unit reacting to changes in its external environment. The component cells are specialized and their activities must be co-ordinated and regulated. This implies some sort of communication between the cells—the transmission of messages controlling their activities and maintaining an optimum balance between them.

In this text we shall study man as an example of a large multicellular animal.

## 18.2.1 Man

Man is a large and complex animal—here we shall approach human anatomy with two very limited aims. First to show very briefly how the vital activities are carried out in an animal. Second to provide the basic information necessary for the treatment of problems of physiological regulation in sections 18.3 and 18.4.

The basic anatomy of man is illustrated in the large coloured diagrams on pages 17, 19, 21, 23. There are more than $10^{14}$ cells in the body and most of them are specialized structurally and/or biochemically. You have already met some specialized cells, notably secretory (gland) cells and muscle cells. Refer back to Units 14 to 16 if you have forgotten what these look like.

The specialized cells, as we mentioned in section 18.0, are associated into tissues and the tissues form organs and the organs form organ systems. From your general knowledge and experience, you can identify the functions of many of these systems.

1 Comparison of cubes with sides of 1, 2 and 3 cm:

| *Length of side (L) cm* | *1 cm* | *2 cm* | *3 cm* |
|---|---|---|---|
| *Surface Area* $(6 \times L^2)$ | 6 | $6 \times 2^2 = 24$ | $6 \times 3^2 = 54$ |
| *Volume* $(L^3)$ | 1 | $2^3 = 8$ | $3^3 = 27$ |
| *Area : volume ratio* | 6:1 | 3:1 | 2:1 |

## 18.2.2 Vital activities

We have referred several times to the physiological functions which are characteristic of life. You have already met these, in Units 14 to 17. List them now if you can—there are 7.

1 Feeding (nutrition), which is the acquisition of substances from the environment which are used as sources of energy and also in the process of growth (Unit 15).

2 Growth, which is the increase in size and often also in complexity of the organism (Unit 17).

3 Respiration, by which energy is made available in the organism for all its activities (Unit 15).

Most organisms 'exchange gases' with the environment, absorbing oxygen and releasing carbon dioxide—this is part of the process of respiration. But the actual oxidative generation of ATP occurs in the individual cells by biochemical pathways which you have already studied. Some organisms generate ATP anaerobically.†

2 Comparison of spheres with radius of 1, 2 and 3 cm:

| *Radius of sphere (R)* | *1* | *2* | *3* |
|---|---|---|---|
| *Surface Area* $(4\pi R^2)$ | $4\pi$ | $16\pi$ | $36\pi$ |
| *Volume* $(4/3\pi R^3)$ | $4/3\pi$ | $32/3\pi$ | $36\pi$ |
| *Area : volume ratio* | 3:1 | 3:2 | 3:3 = 1:1 |

4 Excretion, the ejection from the body of waste products of metabolism (Unit 15).

5 Reproduction, the formation of new individuals (Units 17 and 19).

6 Sensitivity (or irritability), the capacity of the organism to react to changes in the environment (Unit 1).

7 Movement, either of the whole organism or of part of it, rapidly or slowly; this is often the most obvious sign of irritability.

Now let us consider how these vital activities are carried out by man.

1 *Feeding* Man is an omnivore, collecting and swallowing animal and vegetable food. The digestive system is shown in the diagram, p. 17.

**List the types of cells which you would expect to be important in this system.**

Gland cells secreting digestive enzymes. Cells to absorb the products of digestion. Muscle cells to move the food along the gut.

2 *Growth* All the tissues of the body grow during infancy and adolescence. Most growth then stops, but there is continuous replacement of cells and tissues in adults.

3 *Respiration*

**Where is the ATP generated during respiration?**

In mitochondria in all the active, live cells of the body.

This is 'tissue respiration'. When we discuss respiration in animals we often mean the 'exchange of gases', that is, the intake of oxygen and output of carbon dioxide from the whole body. You are familiar with this process in Man as 'breathing'.

**List the types of cells which you consider to be important in this.**

Cells lining the lungs, where oxygen is absorbed and carbon dioxide is released. Muscle cells and bone cells used in breathing movements.

4 *Excretion* Waste materials are voided mainly through the kidneys and their associated ducts. Some excretion also occurs through the skin (sweat).

5 *Reproduction* We shall not consider the reproductive system here.

6 *Sensitivity* You have already studied (Units 1 and 2) some human sense organs and some aspects of human responses and behaviour. We shall consider the nervous system in more detail below because of its great importance in co-ordination of bodily activities.

7 *Movement*

**List the cells which you consider to be important in movement.**

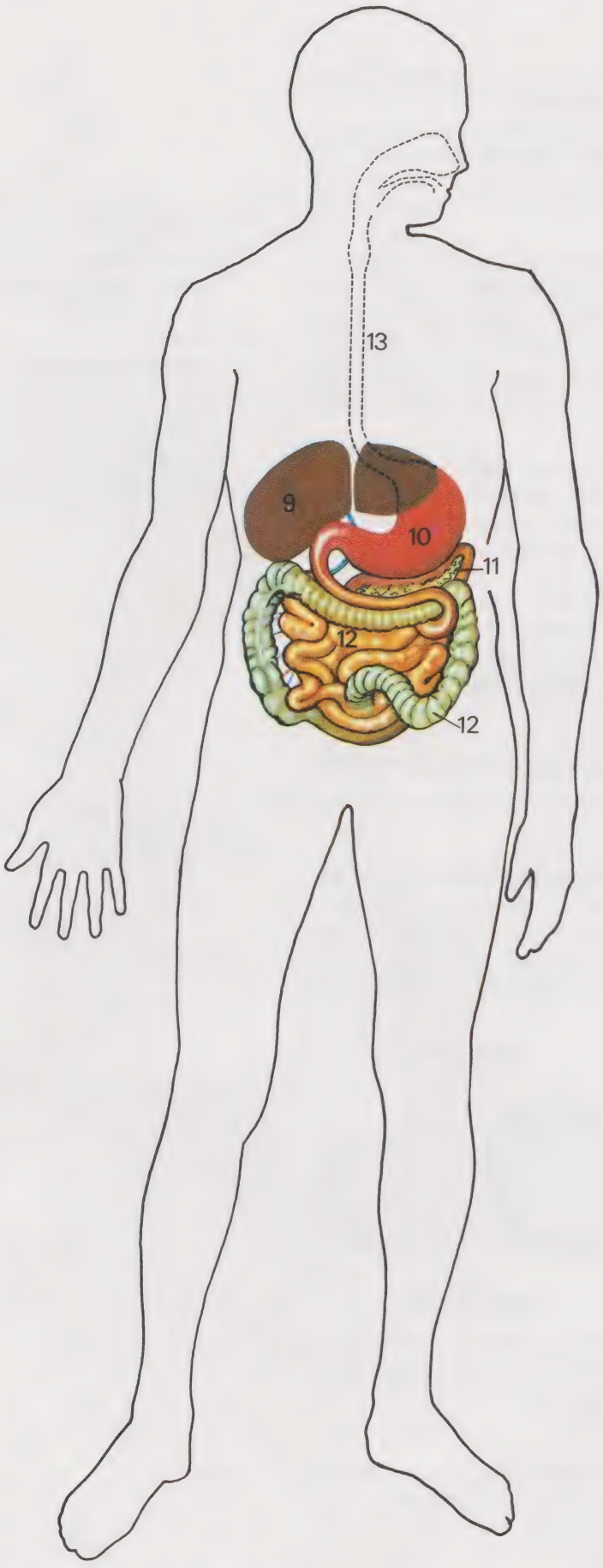
Muscle cells and bone cells—and nerve cells co-ordinating the muscles.

You must realize that we have not included all the organ systems in this list. There are two that we shall next consider: the blood vascular system and the endocrine system. Had we considered growth and reproduction in any detail, we would have mentioned the endocrine system. In omitting the blood vascular system when considering vital activities, we were limiting our definitions of feeding, respiration and excretion to the 'external' level where the substances involved actually enter or leave the cells forming the boundary between body and external world—the lining of the gut and lungs, the kidney tubules† and the skin. But these vital activities also involve all the living cells of the body and the blood plays an essential role as the internal transport system.

Thus there are three organ systems which we have chosen for more detailed study: the blood vascular system (18.2.3), the nervous system (18.2.4), and the endocrine system (18.2.5). All three are important in the regulation of physiological functions which we shall discuss in sections 18.3 and 18.4.

## 18.2.3 The blood vascular system

One of the consequences of the specialization of cells and the grouping of cells with the same specialized function into organs is the necessity for transport within the body of the products of these specialized cells to other cells which may need these products or may be able to dispose of them. We can take feeding as a simple example. Specialized gland cells associated with the gut secrete enzymes and the food is digested in the stomach and intestine. The amino acids, sugars and other substances thus produced are absorbed by specialized cells in the intestine. Ultimately, these substances are required for the metabolism of cells in many other parts of the body.




*The* digestive system (*gut*) *and associated structures fill the front part of the abdomen.*

9. *Liver.*
10. *Stomach.*
11. *Pancreas lying in a loop of duodenum.*
12. *Folds of small and large intestine supplied by blood vessels (shown only on right-hand side of body).*
13. *Oesophagus leading from cavity of mouth to the stomach. (This is shown with dashed lines because it lies much closer to the back than the other structures shown in this overlay.*

From your general knowledge, you may be able to answer the following questions.

**(a) How are the products of digestion of the food transported from the absorptive cells of the intestine to the body cells?**

**(b) What organ carries out 'intermediary metabolism' (you met this phrase in Units 15 and 16), converting the products of digestion into others?**

**(c) Where and how are substances stored for later use?**

(a) Most are carried in the blood vascular system but some are carried in another system called the lymphatic system (which we shall not consider further).

(b) The liver.

(c) As glycogen in the liver—this is easily converted into glucose which can be used by all body cells in cell respiration (Units 15 and 16). Also, as fat under the skin, and round some organs of the body (Unit 16).

We shall consider the blood vascular system from the point of view of transport of substances between groups of cells in different parts of the body. In a very small and simple multicellular animal, substances can move by the physical process of diffusion, but this is slow and so is only effective over very short distances, less than 0.5 mm. Most animals large enough to be seen by the naked eye have some form of blood vascular system.

In man, one of the functions of the blood (as we shall show in section 18.4.3) is the transport of heat from actively metabolizing cells (where heat is being produced as a result of exothermic reactions) to other parts of the body. You may find it helpful now to compare the blood vascular system with a central heating system where water is circulated through pipes from the boiler round the building and back to the boiler—through a 'small-bore' system. Some houses have a 'gravity' circulation without a pump and with pipes of larger diameter, but the 'small-bore' systems have pumps and show analogies with the human blood circulation.

**Bearing this in mind, what component parts would you expect to find in a blood vascular system?**

Tubes conveying fluid and a pump or pumps circulating the fluid.

The circulating fluid is called 'blood'. The pump is called the 'heart.' The tubes are called 'arteries', 'veins' and 'capillaries'. These terms are used to describe blood vessels of different sizes (bores) and with different types of wall. Capillaries are very narrow tubes through the walls of which exchange of substances can occur between the fluid blood and the body

**capillaries**

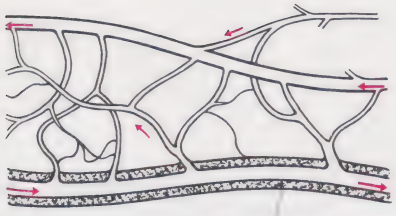


*Figure 2 Diagram to show a capillary network between a small artery and small vein. The arrows show the direction of blood flow.*

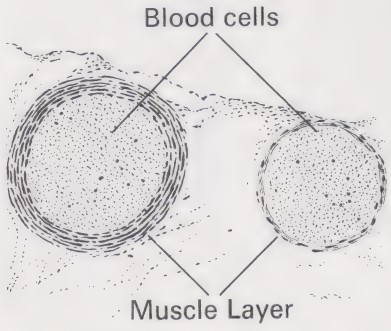


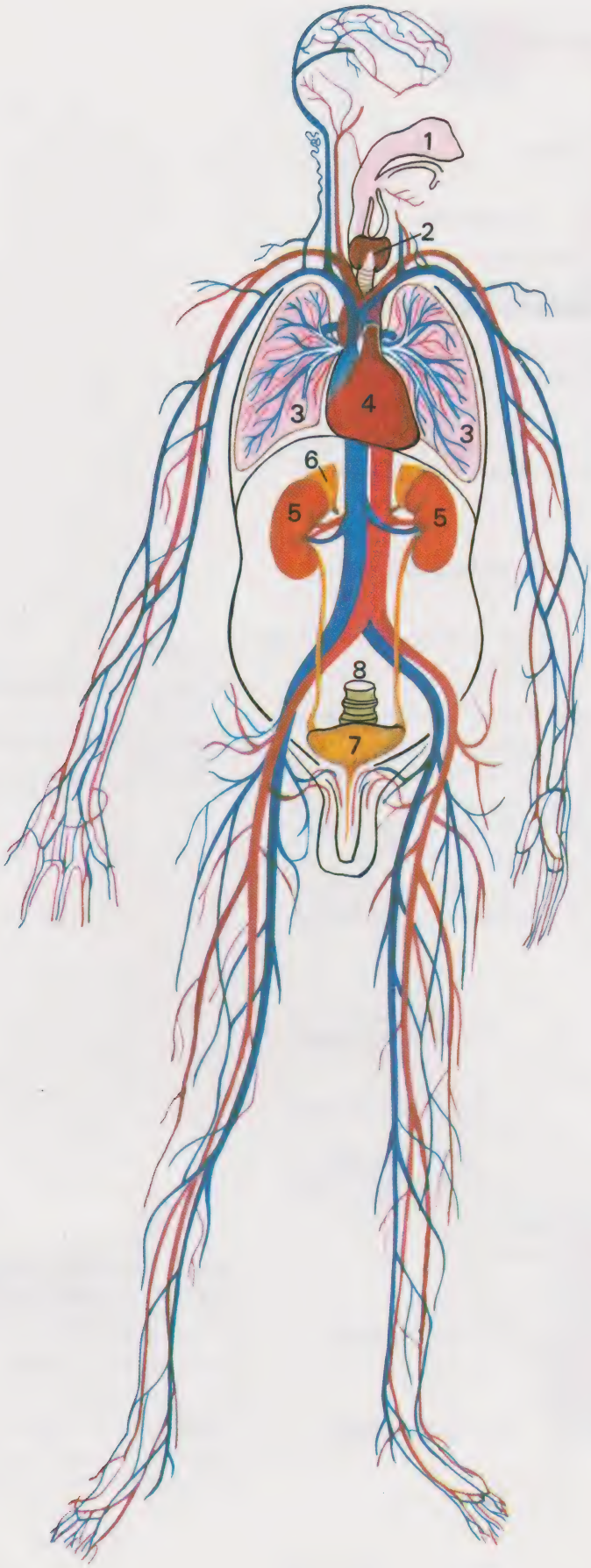

*Figure 3 Diagram of sections cut through an artery (a) and a vein (b) to show the difference in thickness of the walls.*

cells (Fig. 2). Arteries have muscular walls which may assist in pumping the blood and are vessels of wider diameter; they convey blood from the heart to capillary systems (Fig. 3). Veins have walls with much less muscle but with valves at intervals so that the blood flow is uni-directional (Figs. 3 and 4); they collect blood from capillary systems and usually convey it to the heart. However, some vessels form 'portal systems', collecting blood

**arteries**

**veins**

**portal systems**




*The* blood system (*red for arteries, blue for veins*), lungs, kidneys *and associated structures.*

1. *Cavity of nose.*
2. *Thyroid gland situated beside and in front of trachea.*
3. *Lungs.*
4. *Heart (consult Figure 6 for details of vessels close to the heart).*
5. *Kidneys.*
6. *Adrenal glands.*
7. *Urinary bladder, with ureters leading into it from kidneys.*
8. *Cut end of rectum leading to anus.*

from one system of capillaries and transporting it to another without passing through the heart (Fig. 5).

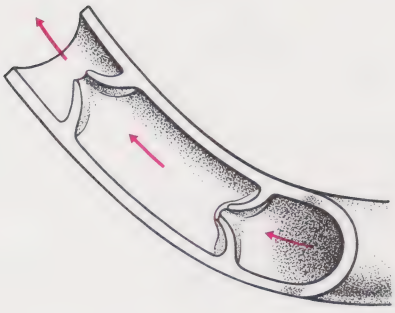


*Figure 4 Diagram of a vein slit open lengthways to show the valves inside it. The arrow shows the direction of blood flow.*

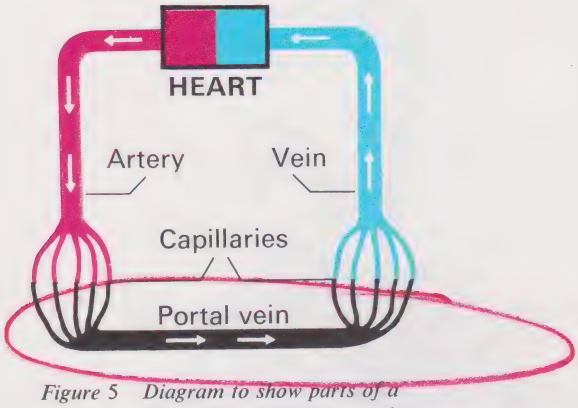



*Figure 5 Diagram to show parts of a single blood circulation. The arrows show the direction of blood flow. Arteries are coloured red; portal veins are coloured black; other veins are coloured blue; the heart is shown divided into two chambers.*

**Comparing the blood vascular system with a central heating system, what parts are analogous with:**

**(a) capillaries, (b) arteries, (c) veins?**

(a) radiators,

(b) pipes leading from the pump to the radiators,

(c) pipes leading from the radiators to the pump.

The heart (Fig. 6) consists of four chambers and has two streams of blood passing through it simultaneously, the two left chambers being completely separated from the two right chambers. Those on the left have received blood from the lungs, so there is plenty of oxygen in this blood. Those on the right receive blood from the rest of the body so there is little oxygen but much carbon dioxide in it; this blood is sent to the lungs whereas the blood from the left side is sent to the rest of the body. This type of blood flow is called a 'double circulation'. Figure 7 is a diagram of the human circulation.

heart

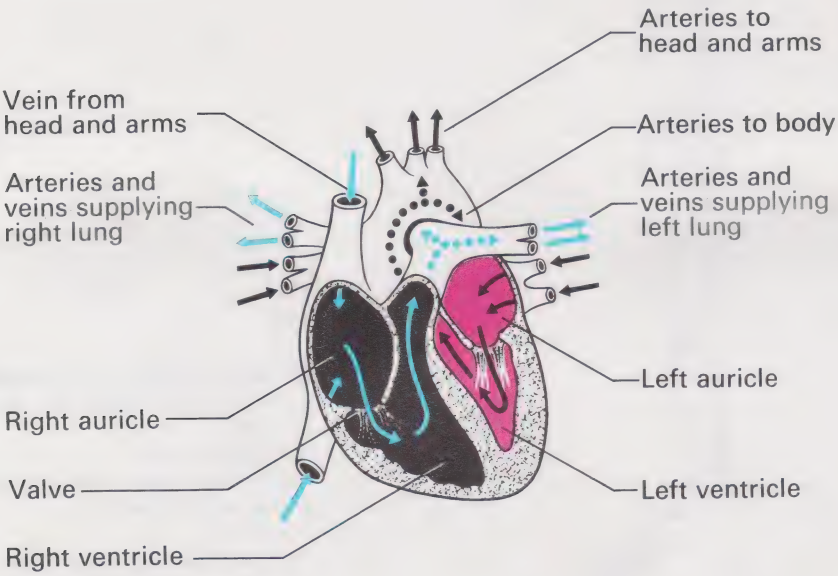
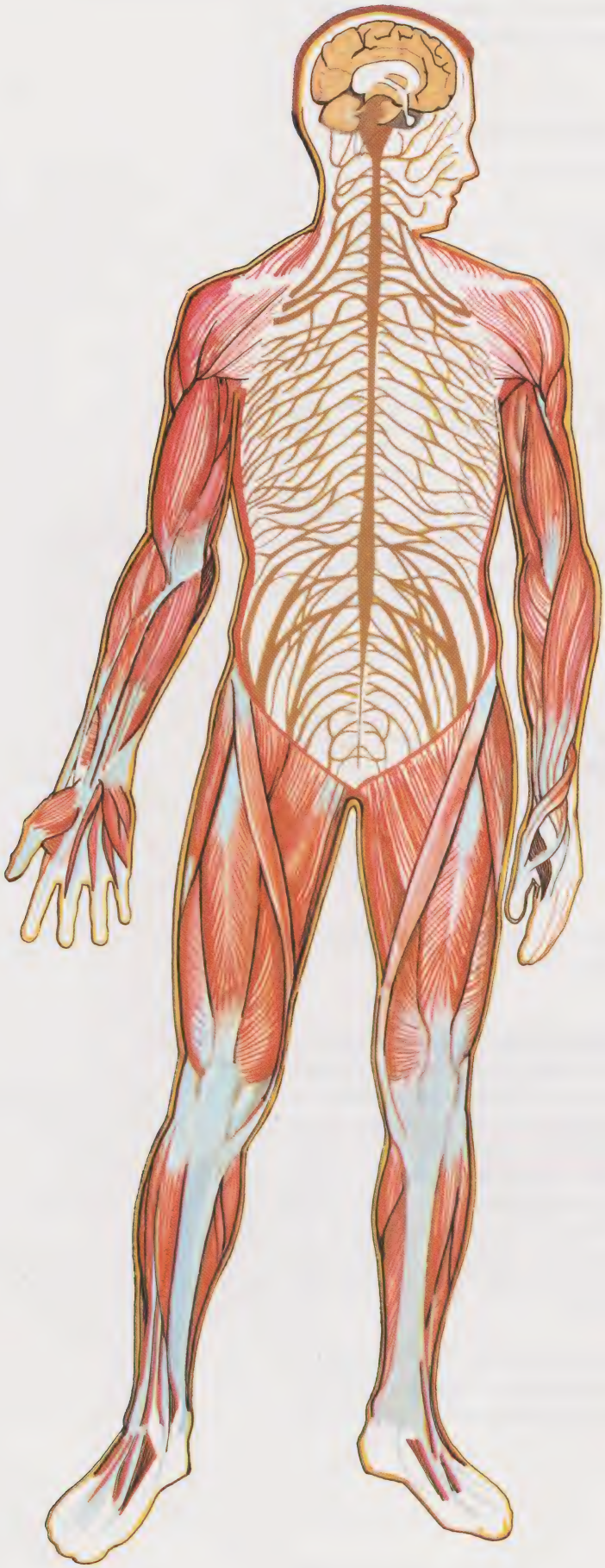



*Figure 6 Diagram of a human heart cut open lengthways and viewed from in front. The blood vessels leading to and from the heart are shown cut close to it; the arrows show the direction of blood flow. The cavities of the left side of the heart and the blood vessels leading to and from them are coloured red; the equivalent cavities and blood vessels of the right side are coloured blue.*

We shall study the musculature of the heart and the control of the heart beat in sections 18.3.2, 18.3.3 and 18.4.2. The blood consists of a fluid portion, which is called 'plasma', and cells. The two principal types of cell



*The* nervous system *is shown in yellow. You can identify parts of the brain by comparison with Figure 23. Note the regular arrangement of nerves emerging from the spinal cord; these are not followed beyond the edge of the drawing of the trunk and neck. The autonomic nervous system is not shown.*
*The* muscles (*red*) *and* tendons (*blue*) *are shown for the limbs only.*

red blood corpuscles

are illustrated in Figures 8 and 9. The red blood corpuscles are so called because they contain the red pigment, haemoglobin; most of the oxygen which is absorbed through the lungs is carried in combination with this

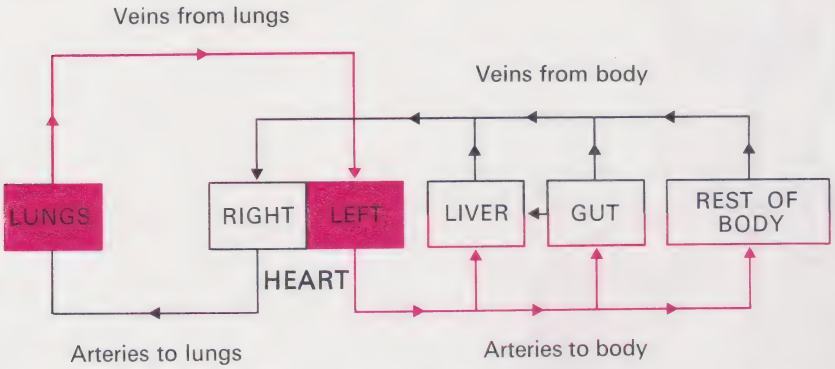



*Figure 7 Diagram of the human blood circulation. Blood vessels containing blood with much oxygen are coloured red; blood vessels containing blood with little oxygen are coloured black.*

white blood corpuscles

haemoglobin. There are about $5 \times 10^6$ red corpuscles per $cm^3$ of whole blood; they are unusual cells in having no nuclei. The white blood corpuscles have nuclei and are part of the protective mechanism of the body against bacterial and other foreign cells. There are about 7 000 per $cm^3$ of whole blood.

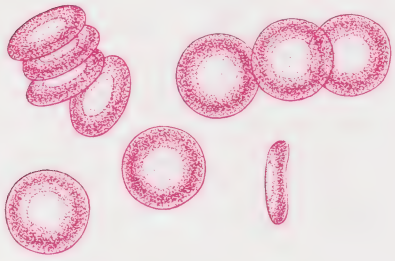


*Figure 8 Red blood corpuscles from human blood, magnified.*

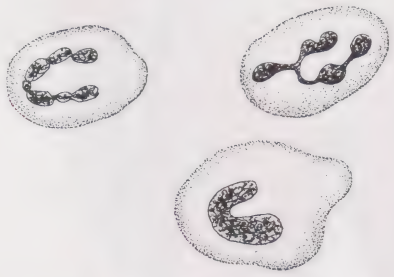


*Figure 9 White blood corpuscles from human blood, magnified.*

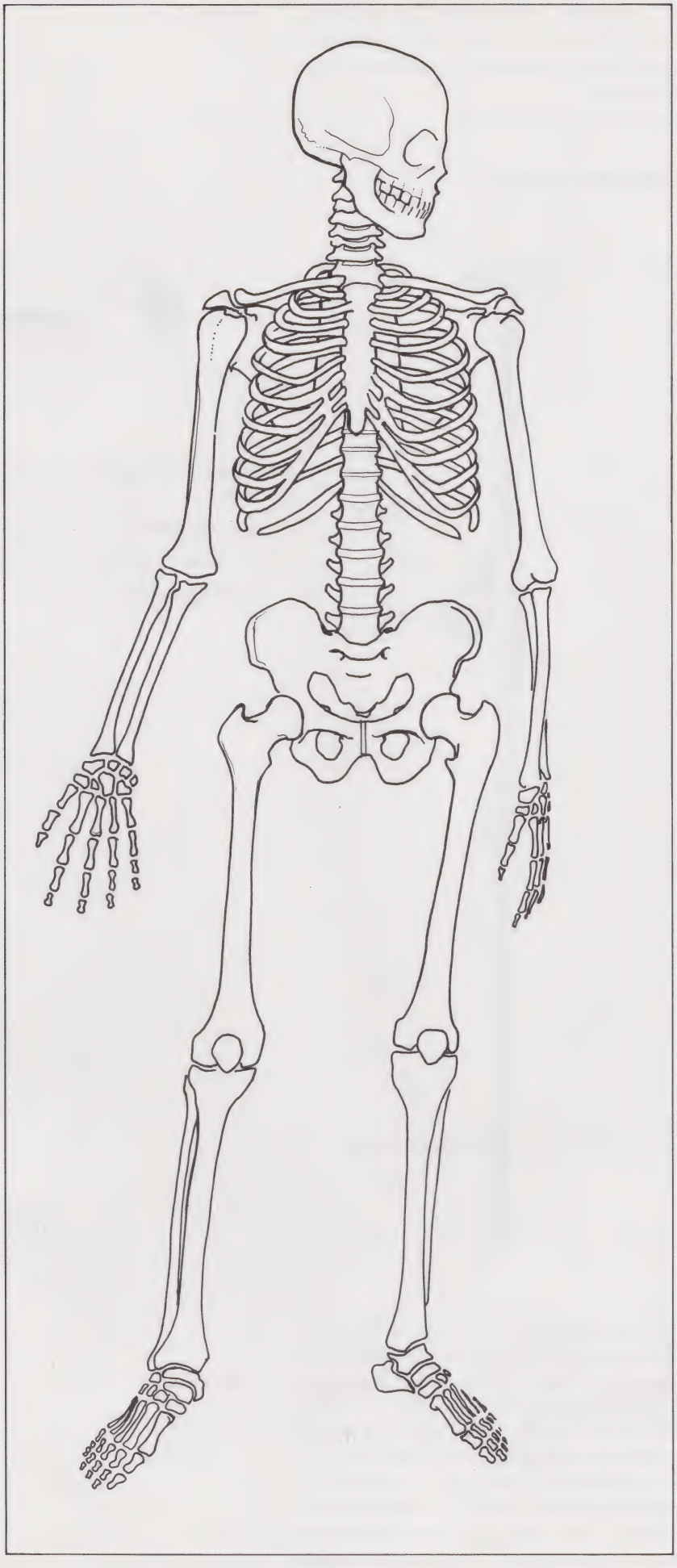
blood plasma

Blood plasma is 91 per cent water and contains about 7 per cent of protein in solution. The other 2 per cent comprises other organic substances and inorganic salts. Glucose, amino acids and other products of metabolism are carried in solution. The majority of body cells are bathed in plasma which forms the immediate environment outside the cell membrane. It is essential for the well-being of these cells that the environment should remain relatively constant. There are physiological mechanisms which ensure this, but we shall consider one of them only in this Course. In section 18.4, we shall discuss the control of body temperature and shall then refer again to the function of the blood in the transport of heat and the maintenance of an internal environment of constant temperature.

Now take out your film viewer and examine film strip 18(c), reading the figure legends (p. 94) carefully as you look at the photographs. Compare these photographs, made from real microscope slides, with Figures 2, 3, 4, 6, 8 and 9 in this section of text.

### 18.2.4 The nervous system

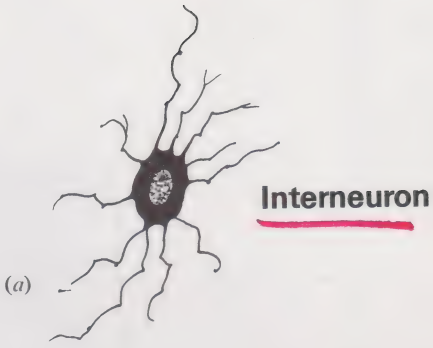
We have mentioned the nervous system in connection with sensitivity (the response to stimuli) and locomotion (in co-ordination of the activity of muscle cells). The cells which carry out these functions are the nerve



*A human skeleton*

cells or neurons. These are usually associated with supporting and protective cells and together all these cells form the brain, spinal cord and nerves. Each neuron consists of a cell body containing the nucleus and a series of processes or fibres arising from it.
Typical neurons are shown in Figure 10 (a), (b) and (c).

neurons



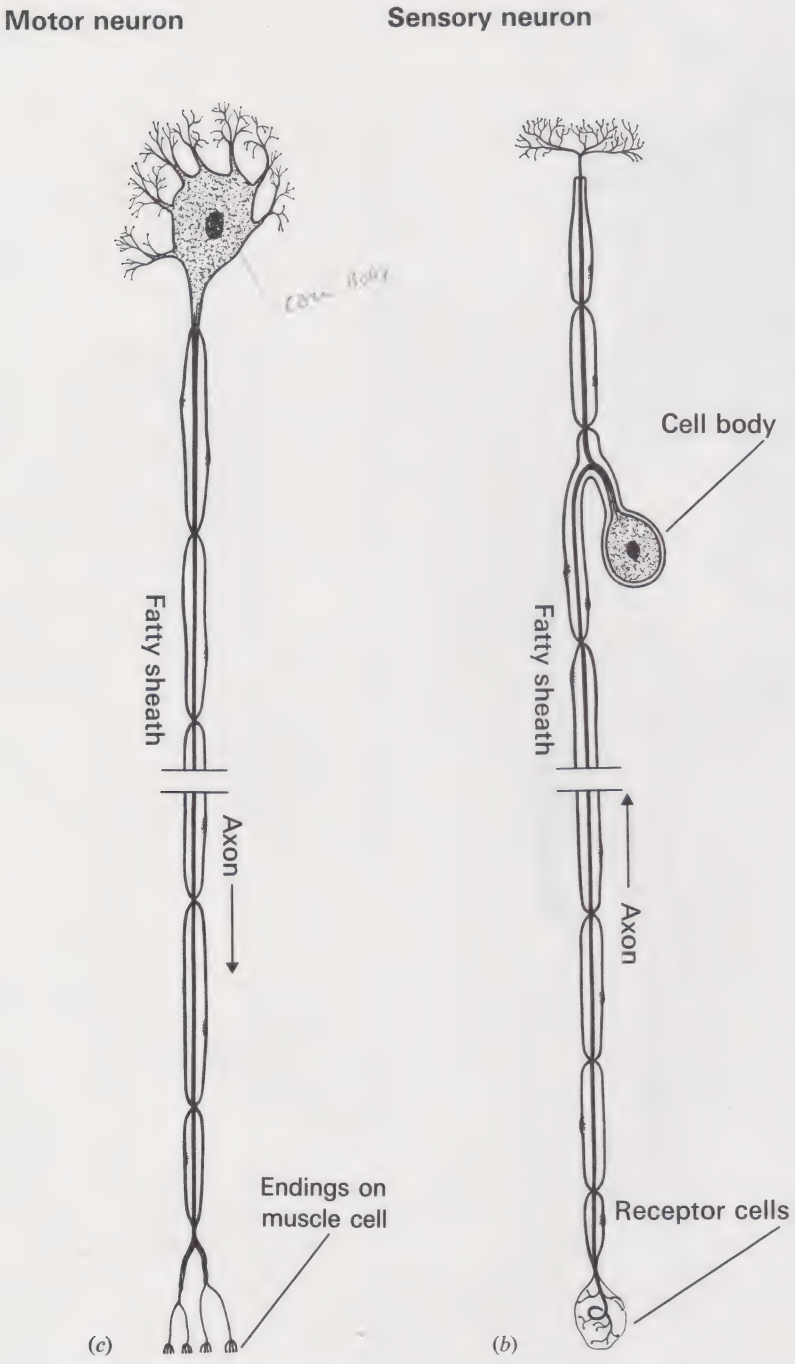




*Figure 10 Diagrams of typical nerve cells.*

(*a*) *Interneuron*

(*b*) *Sensory neuron*

(*c*) *Motor neuron*

Figure 10 (a) shows a type of cell found in the brain and parts of the spinal cord—note the many branching processes in all directions—we shall refer to this sort of cell as an 'interneuron'. Figure 10 (b) shows a sensory neuron, which conveys messages from receptors (sensory cells) to motor interneurons in the spinal cord or brain. Figure 10 (c) shows a motor neuron, which conveys messages from interneurons in the spinal cord or brain to effectors such as muscle or gland cells. In Figure 10 (b) and (c) the size of the cell body has been exaggerated compared with the length of the main process, which is called the axon. The axon is surrounded by a fatty sheath. It may be more than 1 m long. The cell body has branching

interneuron

axon

processes and is at one end of the axon of a motor neuron, but in a sensory neuron the cell body lies to the side of the axon and has no branching processes. These axons are usually bound together with other types of cells (connective tissue) to form the 'nerves' that are seen when dissecting an animal.

motor neuron
sensory neuron

The messages are conveyed by the nerves as waves of change of electrical potential passing down the axon. The arrows in the diagrams show the directions in which these types of nerve cell usually pass messages. Interneurons may pass them in all directions; sensory and motor neurons can pass impulses in either direction when given electric shocks. The fact that in life messages normally pass in one direction only is a property of the 'synapse'. This is where the processes of one nerve cell come very close to the cell body and processes of another. There is no direct cellular connection between two neurons. Messages reaching sensory and motor neurons normally cross the synapse at one end only of the axon. We shall explain how messages cross synapses later (18.3.4) and shall be concerned with the properties of interneurons in section 18.5. If you want to know more about how nerves transmit messages, you can read *The Chemistry of Life*, pp. 220–5.

synapse

The human nervous system can be divided anatomically, somewhat crudely, into three parts; the brain, the spinal cord and the nerves. The brain contains many thousands of interneurons grouped into 'centres' which are connected with each other by tracts. We shall refer to some of these later, but we will mention here that there are centres (sensory areas) connected with different senses—visual, auditory, taste, etc.—centres connected with different responses (motor areas), and others called correlation centres. The spinal cord includes: ascending tracts, which connect the receptors of the body with sensory areas in the brain; descending tracts, which connect the motor areas of the brain with effectors in the body; and interneurons. Sensory nerves and motor nerves connect sense organs and effectors with the spinal cord; some are directly connected with the brain. Figure 11 is a simplified representation of the arrangements.

correlation centres

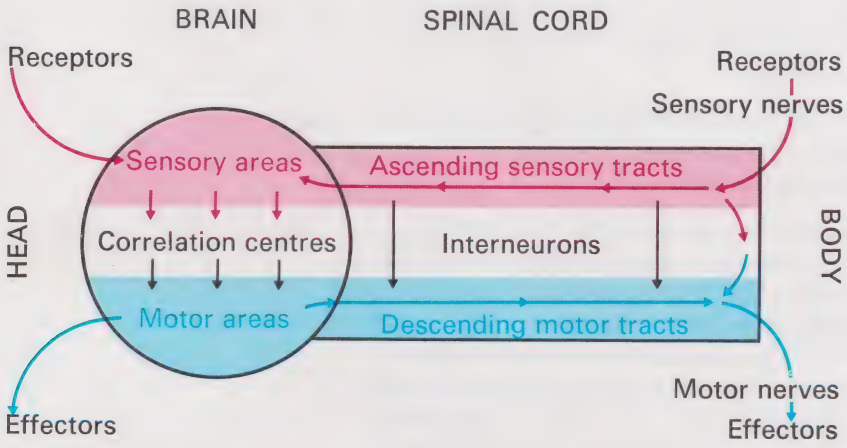



*Figure 11 Diagram to show the basic organization of the human central nervous system. Sensory nerves, tracts and areas are coloured red; motor nerves, tracts and areas are coloured blue; correlation areas are left white.*

Physiologically, the nervous system can also be divided into three parts.

1 The *somatic* nervous system, which is concerned mainly with responses of the whole animal to external situations and so with actions which are 'voluntary'.

somatic nervous system

2 The *autonomic* nervous system, which is concerned with responses of organs within the animal and the performance of functions that are generally not under voluntary control.

autonomic nervous system

**Suggest some of these.**

Secretion of enzymes in the gut, movements of the gut wall, beating of the heart, etc.

3 The *brain centres*, which correlate all the activities of the body.

We shall study the autonomic nervous system in more detail in section 18.3.3.

## 18.2.5 The endocrine system

This system consists of a number of glands (collections of secretory cells) which all have a very good blood supply and pass their secretions directly into the blood plasma.

**How is this different from glands such as the salivary glands?**

These pass their secretions through ducts, e.g. saliva into the mouth.

The secretions of endocrine glands are called 'hormones' (from the Greek, 'to excite'). The organs affected by these hormones are sometimes called the 'target organs'. You can read more about the way in which hormones work at the biochemical level in *The Chemistry of Life*, pp. 201–17.

**endocrine gland**

The hormones circulating in the blood form a system of communication within the body independent of the nervous system—except in so far as the secreting activity of some endocrine glands is under nervous control. Many aspects of growth and reproduction are under hormonal control, so the endocrine glands are vital for survival and normal life.

**hormones**

Here we shall consider only three endocrine glands: the adrenal, the thyroid and the pituitary. They are shown in the diagram of man.

The adrenal glands are a pair of pea-sized organs situated close to the kidneys and they have two layers, cortex and medulla, both of which secrete hormones. In section 18.3.4 we shall consider the effects of adrenalin, the hormone of the adrenal medulla.

**adrenal gland**

The thyroid gland has two lobes, one on either side of the windpipe; the two are joined immediately below the voice-box. It secretes only one hormone, thyroxin, which contains iodine (18.3.4).

**thyroid gland**

The pituitary gland is a small round body connected to the underside of the brain just behind the crossing of the optic nerves as they pass in from the eyes to the brain. It is sometimes called 'the master gland', because it produces hormones that affect many of the other endocrine organs of the body. Here, in section 18.3.4, we shall be concerned only with the pituitary hormone as it affects the thyroid gland. Pituitary hormones that affect the reproductive system (the gonadotrophins) are now used in controlling human fertility, either to depress it (some contraceptive pills) or to promote it (fertility drug).

**pituitary gland**

Section 18.2 is an account of some features of human anatomy. The blood vascular system, nervous system and three endocrine glands are chosen for special treatment because they play important roles in the control of physiological functions—the topic covered by section 18.3.

*Now you can do* SAQs *3 to 5*.

Later, in section 18.5, we shall compare the nervous system and the endocrine system as regulatory and co-ordinating systems.

## 18.3 Physiological Regulation in Man

Each man is an individual, a single organism, who normally reacts as a unit to external situations. This could not happen if all the cells within the human body behaved as independent individuals. Most of these cells are specialized and perform certain functions but are incapable of performing others; so the ability of the whole man to carry out the vital activities depends on the co-operation of many cells of different types. In this section we shall study the three principal types of co-ordination to be found in the human body:

1 cells within an organ acting directly on each other (18.3.2);

2 co-ordination through the specialized cells of the nervous system (18.3.3);

3 co-ordination by means of chemical substances secreted by the specialized cells of endocrine organs into the blood (18.3.4).

### 18.3.1 Homeostasis and teleology

Some of you may find it helpful to compare the human body with a community of people (as we did earlier, 18.0). The success of the community depends on the degree of co-operation between the individuals within it. If the community is producing something, then there must be an individual or a committee planning the operation, and it is likely that a really efficient committee would construct 'flow sheets' to plot the progress of components. There is a need for a 'feedback' system of information and control, so that all the different processes are carried out with maximum efficiency and with no waste of labour or materials.

When there is an equilibrium between the metabolic processes within an organism, and there are regulating processes operating to maintain optimal conditions, then there is a state called '*homeostasis*' (from the Greek words for 'like' and 'standing'). Homeostasis operates in all organisms, and is absolutely essential for the survival of active, complicated animals. It can occur only when there is efficient feedback and regulation of all the physiological processes of the animal. The equilibrium maintained is such that the internal environment supplies optimal conditions for the body cells.

homeostasis

**Recall a similar phenomenon from Unit 16.**

Refer back to the discussion of intracellular regulation.

Thus for the organism, as for the single cell, one of the overriding factors governing behaviour is the existence of systems that maintain the constancy of its internal environment. Much of the internal economy of the organism seems devoted to this end. Those nineteenth-century philosophers who argued that life was governed by divine laws, distinct from those of chemistry and physics, would have claimed that this self-regulating property of homeostasis is evidence that the body was designed and that its properties could be understood only if we ascribed a purpose to them: 'the plant grows upwards in order to reach the sun'. Such arguments as to the purpose of particular actions are described as 'teleological' (noun, teleology), and scientific purists object to them on the grounds that it is both misleading and inaccurate to argue from purpose in this way.

teleology

'Purpose' and 'design' are words perhaps better applied only to human activities and only at the psychological or creative level, as they have a significance which is inappropriate to other situations. Nonetheless, although it is strictly speaking wrong to use teleological arguments in scientific discussions, and respectable scientific publications would not permit them, some biologists use them as a more dramatic form of statement. It is therefore important that you should recognize a teleological argument.

**Which of the following statements are teleological, and which are not?**

1 **The stomach secretes the enzyme pepsin in order to digest proteins in the food.**

2 **The amount of glucose in the blood leaving the liver is controlled by the action of hormones on the liver cells.**

3 **The heart beat increases during exercise so that more blood can reach the muscles.**

4 **During sleep the metabolic rate is low and little energy is used up by the body.**

1 and 3 are teleological; they can be rewritten as follows.

1 The stomach secretes the enzyme pepsin; this digests proteins in the food.

3 The increase in heart beat during exercise means that more blood reaches the muscles.

These are now statements of fact with no suggestion of motive.

**How could you express the following statement in non-teleological form: 'The skin capillaries contract in order to reduce heat loss'?**

'Heat loss is reduced when the skin capillaries contract' or 'contraction of the skin capillaries results in a reduction of heat loss'.

The temptation to use teleological descriptions is particularly strong when discussing the control processes that occur within the body, and co-ordination through the central nervous system in mammals and man. But there is no need to use teleology, though it may serve as convenient shorthand.

In section 18.4 we shall study three systems in man illustrating different mechanisms of feedback and homeostasis. First, however, we must look at the three types of co-ordination listed in the first paragraph of this section.

1 How cells within an organ may act directly on each other is illustrated here by studying the muscles of the heart.

2 Co-ordination through the nervous system is illustrated by the effects of the autonomic nervous system on the rate of heart beat.

3 As examples of co-ordination, using hormones, we shall study the effects of adrenalin on the heart and the control of thyroxin secretion by a pituitary hormone called thyroid stimulating hormone (TSH).

### 18.3.2 Cardiac muscle and the heart rate

The heart was described in section 18.2.3. The contractile tissue in its walls is called cardiac muscle (Fig. 12 (a)). Under the microscope it looks slightly different from skeletal muscle (Fig. 12 (b)), such as that in the arm and legs, and from visceral muscle (Fig. 12 (c)), such as that in the gut walls. Its most characteristic physiological feature is that it contracts, exerting a moderate amount of tension and it does not readily 'fatigue' (stop, exhausted), Unit 15. After each contraction, the muscle relaxes and then it contracts again after a definite interval.

A heart removed from a body continues to 'beat' provided that certain precautions are taken to keep it warm and moistened with a special fluid. As a result of observations on hearts of rats and other mammals, isolated from their bodies, we can make some assumptions about the heart beat in man. The behaviour of the human heart in the body can be observed directly by listening to it through a stethoscope,† by recording electrical changes, using a machine called an electrocardiograph,† and by recording pressure changes in its four chambers, using another special device.

Examine Figure 13, which shows typical pressure and electrical changes during one heart beat.

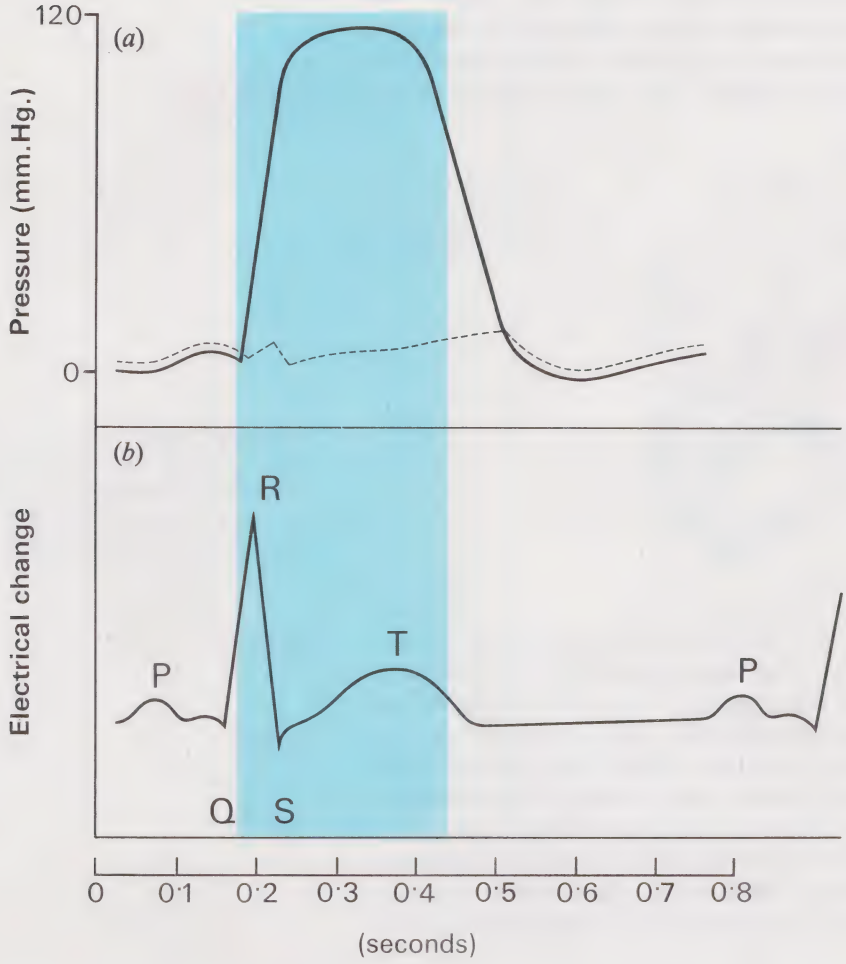



*Figure* 13 *Diagrams to show typical changes in pressure and in electrical potential during a single human cardiac cycle.*

(*a*) *Changes in pressure. Full line—pressure in the ventricles; dashed line—pressure in the auricles.*

(*b*) *Electrocardiogram. The letters are those in normal use for referring to different parts of the cycle. P, R and T are changes in the positive direction, Q and S are changes in the negative direction from the resting potential.*

*The two parts of the figure are synchronized and the blue background shows the time period during which the muscles of the ventricle are contracted.*

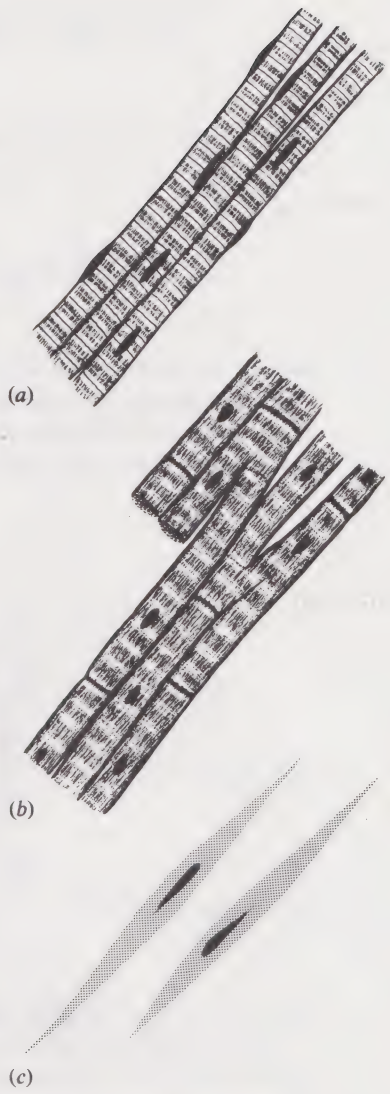



*Figure* 12 *Diagrams of muscle cells magnified.*

(*a*) *Skeletal muscle.*

(*b*) *Cardiac muscle.*

(*c*) *Visceral muscle.*

*Answer the following questions.*

**(a) How long is the single cycle shown in Figure 13?**

**(b) What is the period between the beginning and the end of ventricular contraction?**

**(c) Does the auricle show large pressure changes?**

**(d) Is there a relation between the electrocardiogram and the pressure changes? Use the letters to identify the changes.**

(a) 0.75 seconds.
(b) 0.3 seconds.
(c) No.
(d) The QRS peak occurs as the ventricle begins to contract and the T peak as it relaxes.

The P peak on the electrocardiogram indicates the start of the auricle contraction.

**How long is this before the ventricle begins to contract?**

0.1 sec.

So the whole heart contracts for 0.4 sec (half of the total cycle). The electrical changes pass partly from muscle cell to muscle cell, but they are conveyed more efficiently by a system of modified cardiac muscle cells called (after their discoverer) Purkinje fibres. These are arranged as shown in Figure 14.

Purkinje fibres

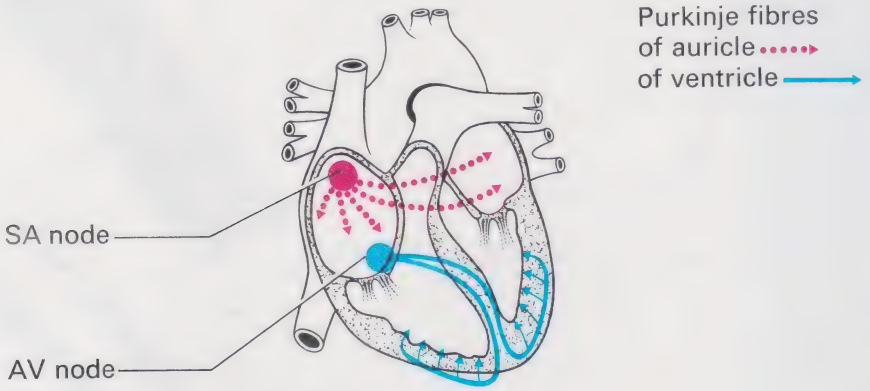



*Figure 14 Diagram of a human heart cut open lengthways. The SA node and associated Purkinje fibres are shown in red; the AV node and associated Purkinje fibres are shown in blue.*

The beat starts at the SA node and the cells of the auricle show a wave of electrical activity (the P wave of the electrocardiogram). As this wave passes along the Purkinje fibres, the muscles of the auricle contract. The AV node is then activated and electrical activity passes along the Purkinje fibres (as the QRS wave) and the ventricular muscles then contract. The fact that the mass of ventricular muscle cells contract simultaneously shows how efficient the Purkinje system is. An isolated heart continues to beat with its rate controlled by the SA node, which is therefore called the pacemaker. If the auricular Purkinje fibres are cut, then the AV node can act as an independent pacemaker, but normally it is controlled by the SA node.

SA node

AV node

The heart can be set up as shown in Figure 15 (see also the photograph in the TV notes) so that its activity can be recorded on a *kymograph*—a slowly revolving smoked drum. Each contraction and relaxation of the heart is recorded as a peak or depression in the tracing made by a lever. An independent time marker leaves another tracing, so that the frequency of contraction can be measured as well as the relative amount of contraction. You will see this demonstrated in this Unit's TV programme.

Look at the kymograph records in Figure 16. The scales for amount of contraction and for time interval are the same on the two records.

**What is the response of the heart to an increase in the volume of blood entering it?**

The amount or strength of the contraction increases.

This is a direct response of the cardiac muscle cells to the stretching imposed on them during relaxation by the flow of blood from the general circulation into the auricles and from the auricles to the ventricles.

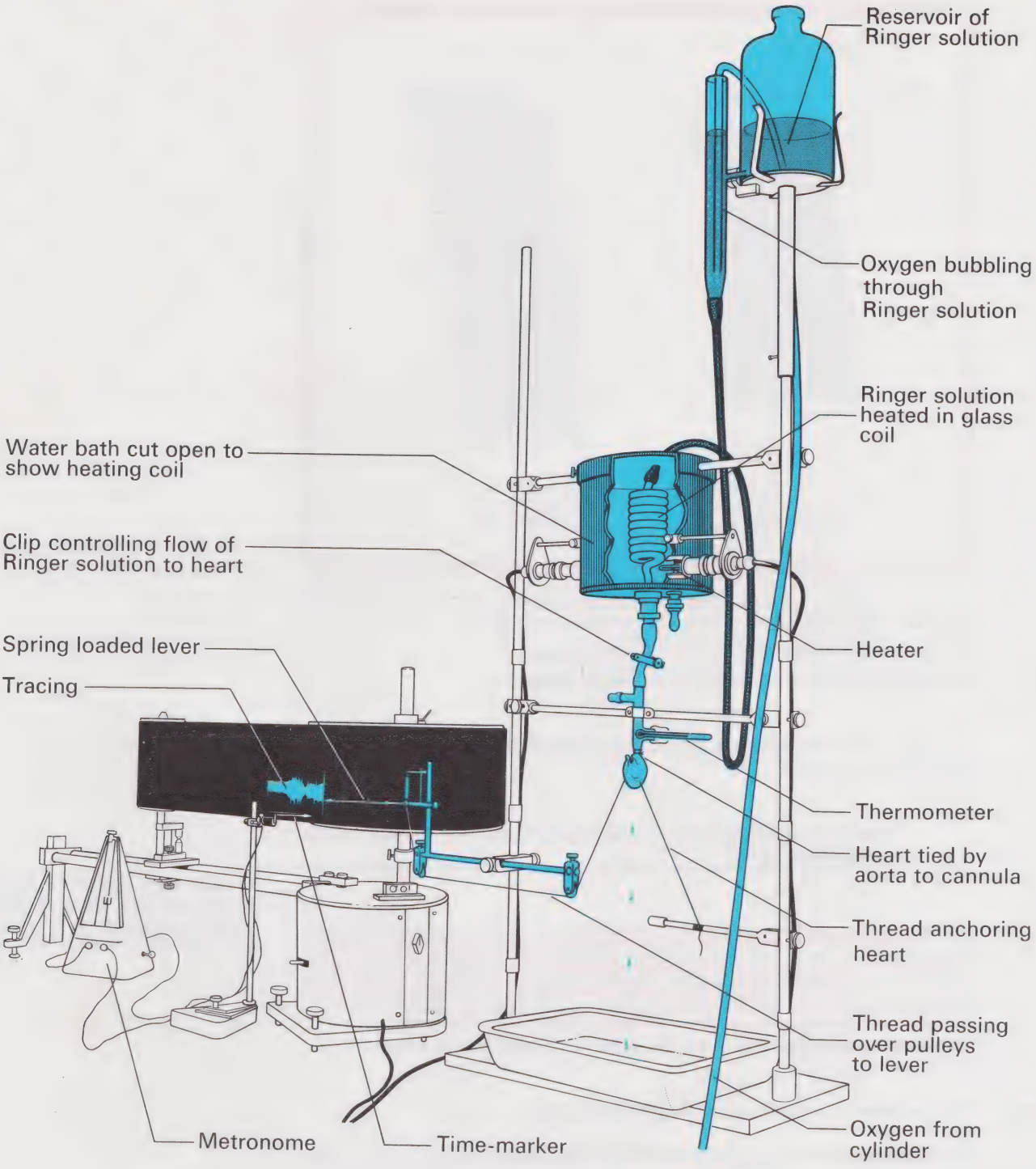



*Figure 15 Diagram of the apparatus used to record the beat of an isolated rabbit's heart. Compare this with the photograph of the apparatus given in the broadcast notes. The parts of the apparatus are labelled. The blue tint shows the support system for the heart (the perfusion fluid called 'Ringer solution' and the oxygen bubbling through it; the water bath bringing it to the normal temperature for rabbit blood) and the mechanical system by which the record is made (the threads steadying the heart and connecting it with the lever which marks the smoked paper on the slowly revolving drum called a kymograph). Note the time marker (a metronome working a lever marking the smoked paper below the trace of the heart beat). The drugs are injected into the perfusion fluid as it passes through plastic tubing immediately above the thermometer. You will see the apparatus in use during the TV programme.*

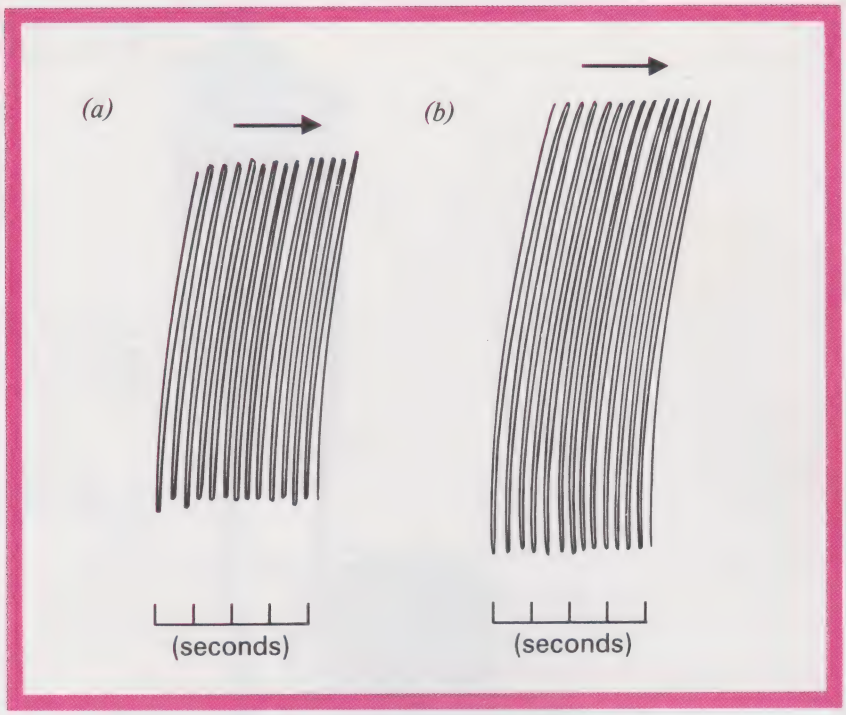



*Figure 16 Diagrams of two kymograph records (smoked-drum records) taken at the same speed and with the same scale showing the amount of contraction.*
*(a) Heart with blood passing through at 5 litres per minute.*
*(b) Heart with blood passing through at 15 litres per minute.*

Contractions of the body muscles during exercise cause an increased flow of blood to the heart.

**What is the effect of the increased output from the heart which results from the stronger contractions?**

Increase in the supply of blood to the muscles and so of metabolites such as glucose and oxygen.

So the cardiac muscle cells act directly on each other, transmitting electrical activity, but with the Purkinje system (of modified muscle cells) giving more rapid co-ordination. Cardiac muscle cells also adjust their strength of contraction to the stretching applied during relaxation.

The heart rate is also under nervous control, as shown in the next section.

### 18.3.3 The autonomic nervous system and the heart rate

The autonomic nervous system was mentioned in section 18.2.4. It is that part of the nervous system concerned with the control of functions not normally under voluntary control. The organs supplied by these nerves are glands, visceral muscles and cardiac muscle. Many have a double nerve supply; the two types of nerves involved are called 'sympathetic' and 'parasympathetic' nerves.

sympathetic and parasympathetic nerves

The two systems of nerves may act antagonistically—that is, if the sympathetic nerve stimulates a muscle to contract more often or more strongly, then the parasympathetic nerve will have the opposite effect and will reduce the frequency or strength of contraction of the muscle. Take the heart beat as an illustration of this.

The parasympathetic nerve to the heart (called the *vagus*) ends near the SA node. When this nerve is active, the SA node sends out fewer impulses, the strength of contractions of the cardiac muscle is reduced, and the interval between the contractions of the auricles and ventricles is increased. The heart rate slows down.

The sympathetic nerves have many endings among the muscles of the heart, but they are concentrated at the SA node and the AV node.

**What will happen when the sympathetic nerves are active?**

The SA node sends out more impulses, so there is less delay between the contractions of auricles and ventricles and the heart rate is more rapid. The strength of contractions of cardiac muscle is increased.

Figure 17 shows three smoked-drum (kymograph) records with similar scales. Figure 17 (a) shows a normal heart beat. Figures 17 (b) and (c) show the effects of applying electric shocks to stimulate the sympathetic and parasympathetic nerves.

**Which of these two (b) or (c) is the result of stimulating the sympathetic nerve?**

(c), which shows increase in strength of contraction and in rate of beat.

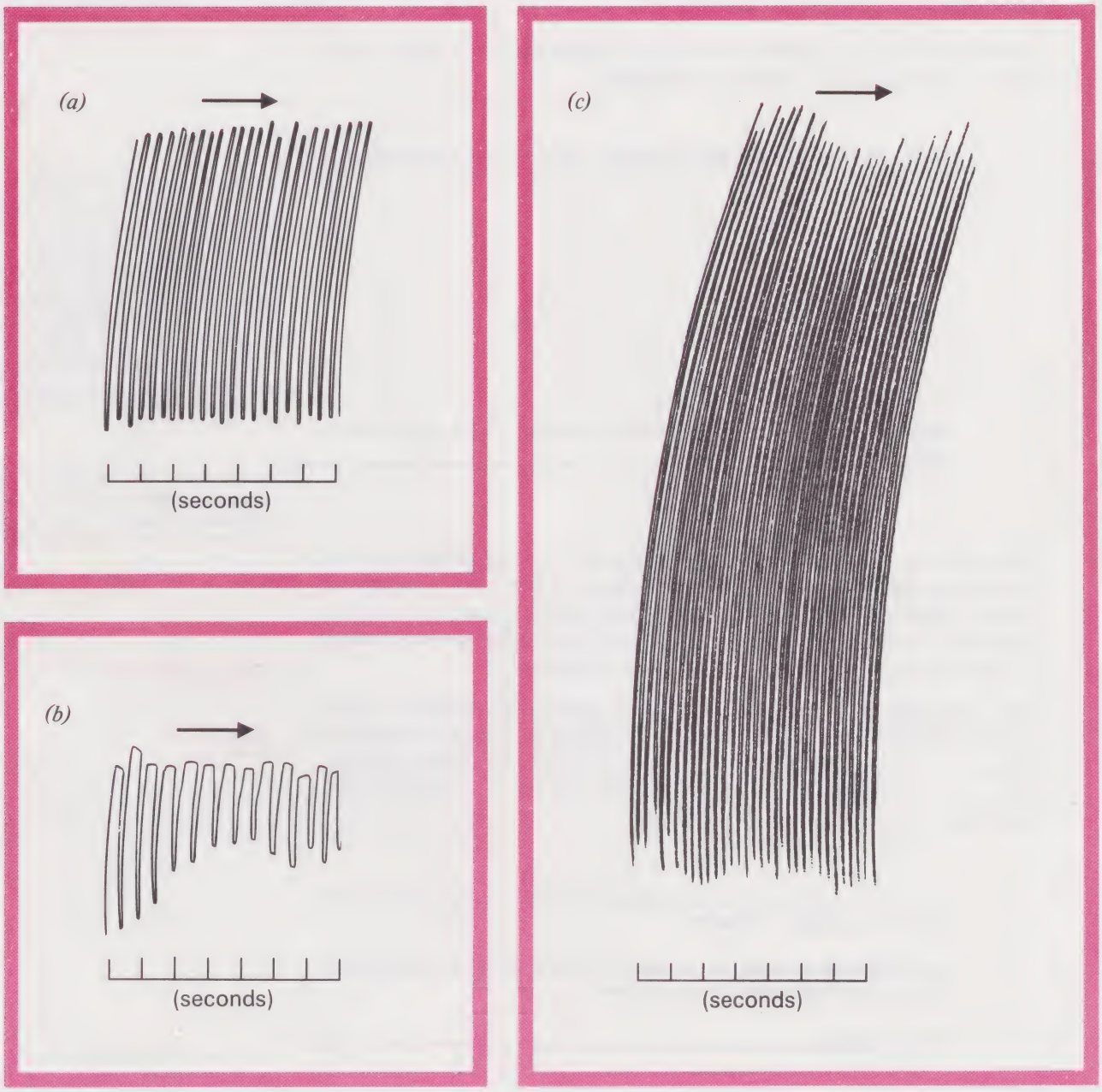



*Figure* 17 *Diagrams of three kymograph records taken at the same speeds and with the same scales showing the amount of contraction. (a), (b) and (c)—see text for explanation.*

The normal range of heart beat in man is from about 40 per minute in sleep to about 70 per minute when sitting, and it may be as high as 150 per minute when a man does hard physical work. This great range of activity is made possible by the character of cardiac muscle and the double control of the heart through the two parts of the autonomic nervous system.

### 18.3.4 Hormones

Read section 18.2.5 again for a brief account of the endocrine system. The three hormones which we have chosen to discuss here present various contrasts. It is important for health and survival, as you will see later, that the level of *adrenalin* in the blood should vary and should be increased rapidly on certain occasions, but that the concentration of *thyroxin* should remain almost constant. Both these hormones have effects on many body cells. *TSH*, however, has a very limited target organ—the thyroid gland.

adrenalin

*Adrenalin*

Sudden fright or any situation when the homeostasis of the body is disturbed may lead to the secretion of adrenalin.

**From your own experience, list the effects it is likely to have on the body.**

It causes: increase in the rate of heart beat; dilation of the pupil of the eye; decrease in the flow of blood to the gut and slowing of the movements of the gut; constriction of the small arteries of the skin and dilation of the arteries supplying the heart and brain; the release of sugar from the liver into the blood; increase in rate of breathing; coldness; 'nervousness'—and so on.

**Does any part of this list of the effects of adrenalin remind you of another system in the body? If so, which?**

Stimulation of the sympathetic nervous system also quickens the heart beat and prepares the body for fight or flight.

The similarity between the effects of adrenalin and of stimulating the sympathetic nervous system is not pure chance. In fact, the sympathetic nerves produce their effect on muscles and glands through a chemical substance which is closely related to adrenalin. This substance is produced at the nerve endings and is called a *chemical transmitter*.

chemical transmitter

The parasympathetic nerves also secrete a chemical transmitter; this is called acetylcholine. The same substance is produced in many other parts of the nervous system and also where motor nerves end on skeletal muscles. You can read more about this, if you wish, in *The Chemistry of Life*, pp. 234–6.

acetylcholine

**What effects would you expect adrenalin and acetylcholine to have on the heart? Look at the tracings in Figure 18.**

**One of these shows the effect of adrenalin; one shows the effect of acetylcholine alone; and the third shows the normal heart.**

**Which is which?**

(c) is the effect of adrenalin,
(a) is the normal heart, and
(b) shows the effect of acetylcholine.

You will see a demonstration of these effects during this Unit's TV programme.

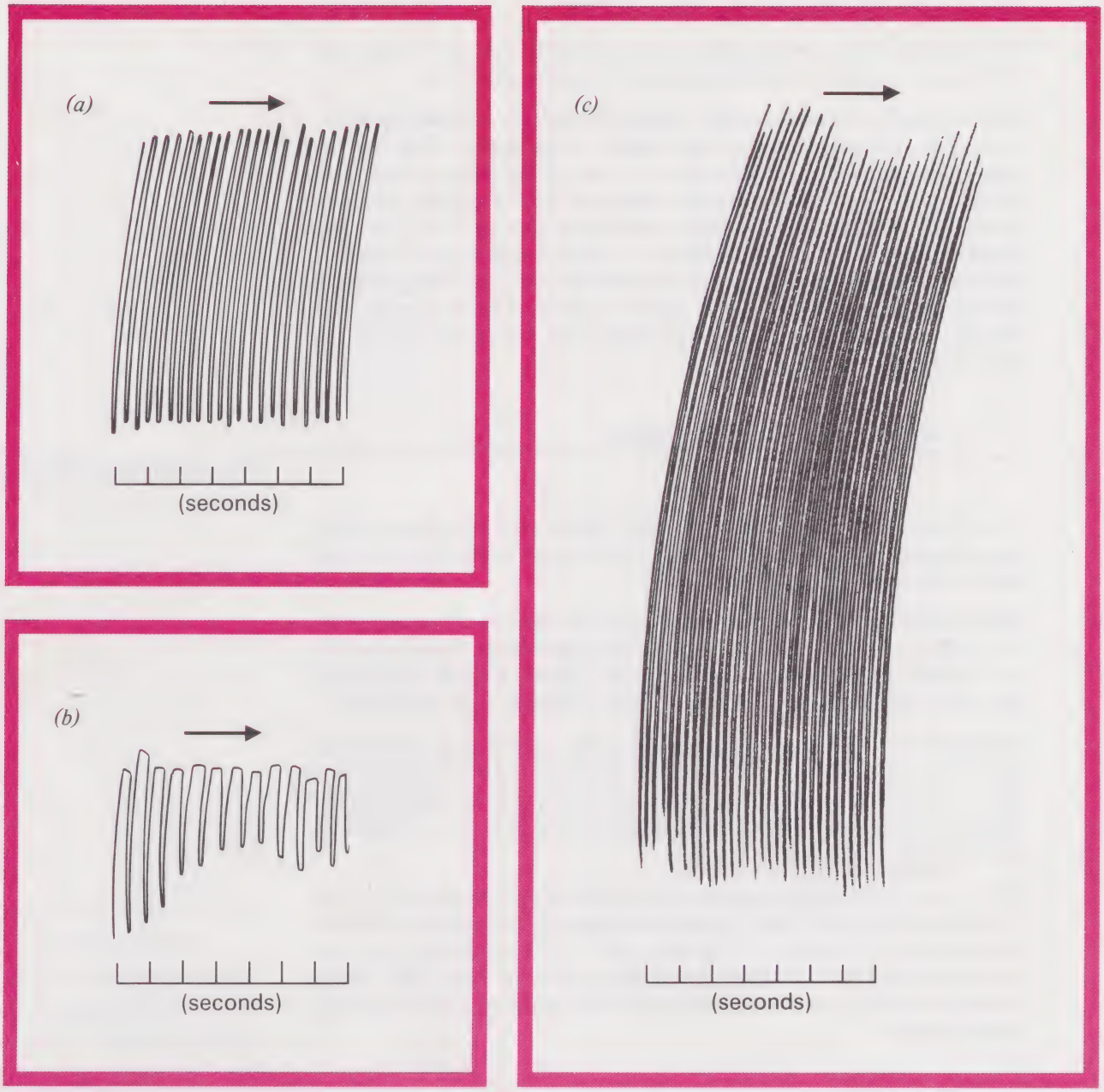



*Figure* 18 *Diagrams of three kymograph records taken at the same speeds and with the same scales showing the amount of contraction. (a), (b) and (c)—see text for explanation.*

All tissues have an enzyme (called cholinesterase) which breaks down acetylcholine; thus the effect of acetylcholine on the heart may be difficult to demonstrate.

You may wonder why there should be two such similar systems—nerves which produce chemical transmitters at their endings very close to effector cells and an endocrine organ which produces a chemical which circulates in the blood and so reaches and stimulates the effector cells. The two systems exert different types of control. Circulating adrenalin will influence all cells that can react to it, whereas the sympathetic nervous system can be used more discriminatingly with some nerves acting and others resting. The sympathetic nerves can be 'switched on or off' more rapidly than the secretory cells of the adrenal medulla, but adrenalin circulating in the blood can maintain a state of emergency throughout the body for comparatively long periods of time with the effects gradually fading away as the adrenalin is destroyed by a specific enzyme. So the principal differences between the two systems are in speed of action and breadth of 'target'.

*Thyroxin and thyroid stimulating hormone (TSH)*

thyroxin

Thyroxin has a very powerful effect on the metabolic rate of all tissues and it influences growth and metabolism over long periods of time.

Lack of thyroid secretion during childhood leads to a condition called 'cretinism'—dwarfing, obesity and mental subnormality. This can be prevented completely by feeding thyroid tissue or the substance thyroxin to the patient. Adults with thyroid deficiency show a peculiar puffiness of the face and muscular weakness, mental dullness and brittle hair. The symptoms are completely alleviated by administering thyroid tissue or thyroxin. 'Derbyshire neck' was once common; it was an enlargement of the thyroid gland (a *goitre*) and it occurred where the drinking water was deficient in iodine. Since table salt nowadays has iodine added to it, this type of goitre is now very rare.

**What has iodine got to do with thyroxin?**

Thyroxin contains iodine (18.2.5).

If the drinking water contains very little iodine, then the thyroid gland cannot manufacture sufficient thyroxin. One reaction to this is the enlargement of the gland forming a goitre.

Some individuals suffer from over-secretion of thyroxin. They are often very active, nervous, irritable, and have a rapid pulse. Some may also have rather prominent eyes (exophthalmic goitre). Surgical removal of part of the thyroid gland may be required to alleviate these symptoms.

Thyroxin has widespread effects on body cells, speeding up metabolism and the production of heat. Too little and too much both cause deleterious effects in man, so it is essential that the secretion of the thyroid gland should be continuous and at an appropriate level. This is controlled by TSH (*t*hyroid *s*timulating *h*ormone).

TSH

TSH is one of the many hormones secreted by part of the pituitary gland. It reaches the thyroid gland through the blood system and has the effect of promoting the release of thyroxin; that is, its conversion from the inactive form which is stored in the gland into the active form which circulates in the blood. It also stimulates the secretory cells to produce more thyroxin.

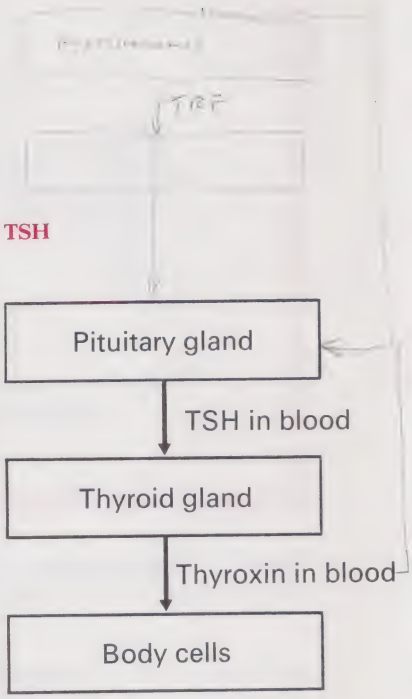



*Figure 19 Flow diagram to show the connection between the pituitary gland and thyroxin reaching the body cells.*

## 18.3.5 Flow diagrams

The relationship between the pituitary gland, TSH, the thyroid gland, thyroxin and body cells can be shown in a diagram (Fig. 19).

This is a type of flow sheet or flow diagram, a device used by production engineers. We can also use the language of information theory (refer back to Unit 16 if you have forgotten what this is) and state that: the pituitary gland instructs the thyroid gland to secrete thyroxin—the instruction is conveyed as a hormone, TSH, and this instruction is translated by the thyroid gland cells into another hormone, thyroxin.

The words in boxes in Figure 20 form part of a flow diagram showing the control of the heart rate.

**Add arrows between appropriate boxes to complete this flow diagram.**

This flow diagram includes the three important types of co-ordination found in the human body. You can make this clear by marking the components in three different ways:

e.g. (a) for the system of cells within the heart acting directly on the cardiac muscles;

(b) for the parts of the nervous system that can alter the rate of the heart beat;

(c) for the hormone affecting the rate of heart beat and the endocrine gland that secretes it.

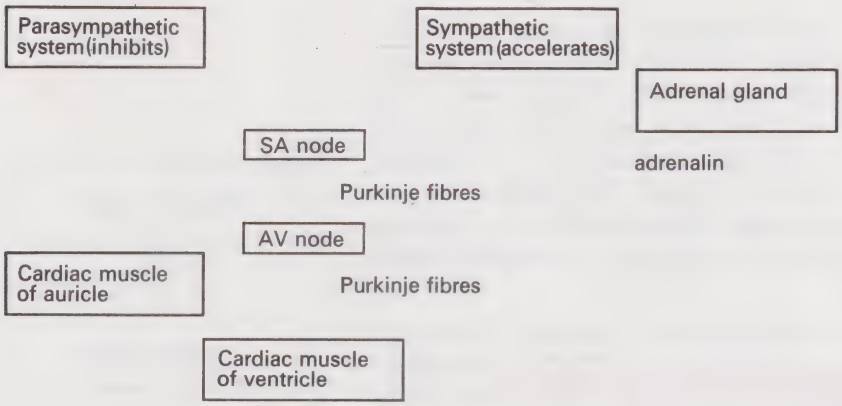



*Figure 20 Flow diagram, with connecting lines omitted, to show the control of the heart rate in man.*

Compare your version with the completed flow diagram in Figure 21.

These two flow diagrams, Figures 19 and 21, summarize the information and ideas in section 18.3.

*You can now attempt* SAQs *6–10.*

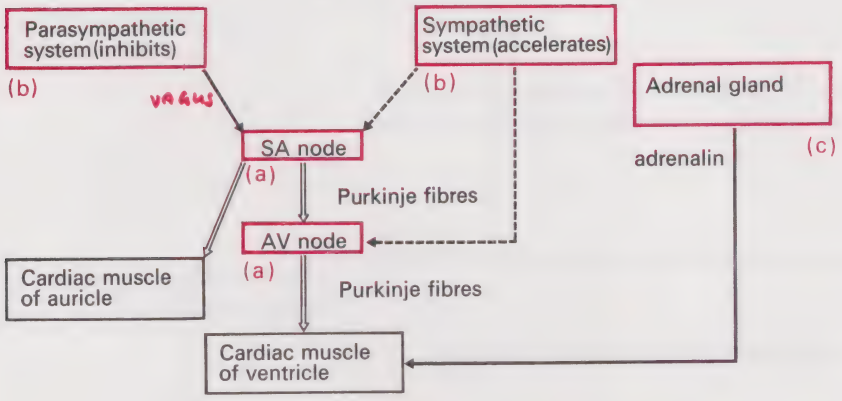



*Figure 21 Completed flow diagram to show the control of the heart rate in man. The relevant components are boxed in red. See the text at the top of the page for explanation of the annotations (a), (b), (c).*

## 18.4 Feedback Systems in Man

To maintain homeostasis—the state of optimum functioning or flow—a feedback system is required to monitor† the flow and regulate the rates of the processes (or activities of the organs). If the thyroxin level of the blood becomes too high or too low, there are adverse effects—the metabolism becomes too rapid or too slow. So there must be an accurate control of the secretion of thyroxin into the blood. This implies that some system monitors the level of thyroxin and responds to changes in level by altering the level of thyroid secretion; that is, there is a feedback system involved.

In this section we shall deal with three types of feedback and control system in man. In the first, the control of the level of thyroxin, the mechanisms are almost entirely hormonal. In the second, the control of the heart rate, the control is partly nervous and partly hormonal. In the third, the control of body temperature, the nervous control mechanism involves conscious action as well as response through the autonomic nervous system.

Do not try to learn the details of the *last two control systems* (the heart rate and body temperature). They should interest you since you can observe them in operation as you go about your daily activities.

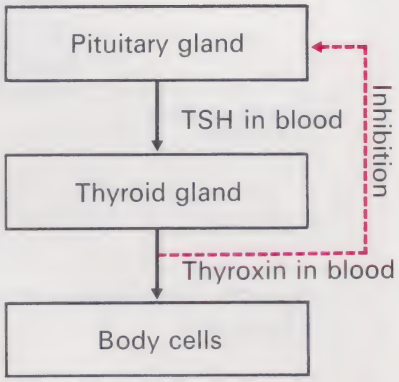



*Figure 22 Flow diagram to show the connection between the pituitary gland and thyroxin, including one feedback loop.*

### 18.4.1 The control of thyroxin level in the blood

**What substance stimulates the release of thyroxin from the thyroid gland into the blood?**

TSH from the pituitary gland.

There is a direct feedback system: an increase in the amount of thyroxin in the blood affects the cells of the pituitary directly so that they secrete less TSH.

**What is the effect of this?**

Less thyroxin is secreted and the level in the blood falls.

**Turn back to Figure 19 and add an arrow to represent this feedback loop.**

Compare your figure with Figure 22. The feedback loop here is an example of inhibitory feedback, since increase of the 'product' (thyroxin) inhibits the production of the 'instructing' TSH. It can also be called a negative feedback loop.

**Suggest what might happen when the level of thyroxin in the blood falls.**

You might think that the pituitary cells would respond to a decrease in level by producing more TSH—this occurs to some extent. The stimulus to raise the level of circulating TSH and maintain this higher level comes

from the brain, from the hypothalamus, an area just above the pituitary gland (Fig. 23).

hypothalamus

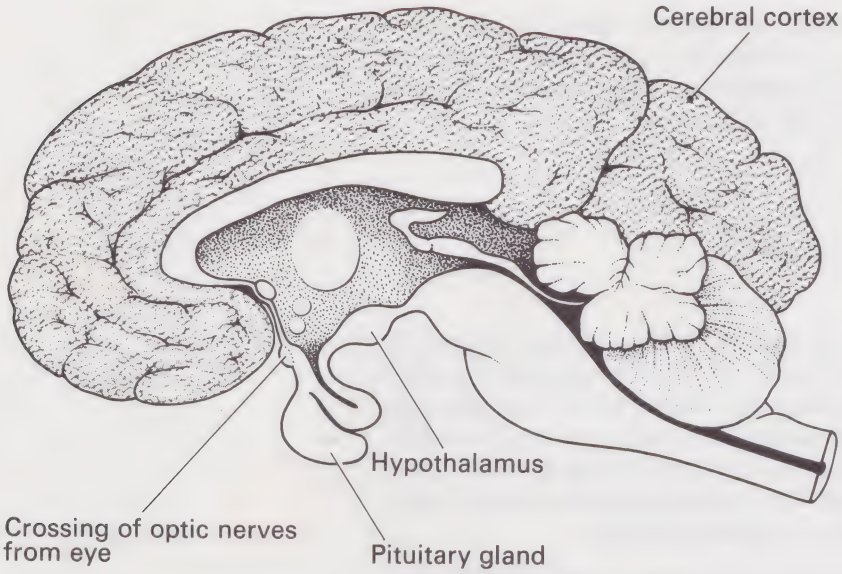



*Figure 23 Diagram of a human brain, cut lengthways, to show the cerebral cortex (stippled grey), the hypothalamus and the pituitary gland.*

You might think that a nerve from this part of the brain would stimulate the pituitary cells—*but this does not happen.*

Some of the cells in the hypothalamus are neurosecretory cells; that is, the cell bodies secrete substances which pass down the axons and are released at the other end (Fig. 24). Some of these cells secrete a substance called TRF (*T*hyroid *R*eleasing *F*actor) and this is passed into capillaries which form part of a portal system (if you cannot remember what this is, look back to section 18.2.3). A very short portal vein (Fig. 25) carries TRF to the pituitary gland and forms capillaries there from which the TRF is taken up by the cells which secrete TSH. When these cells take up TRF, they secrete TSH. This is released into the capillaries and passes from the pituitary to the heart and thence round the body and to the thyroid gland.

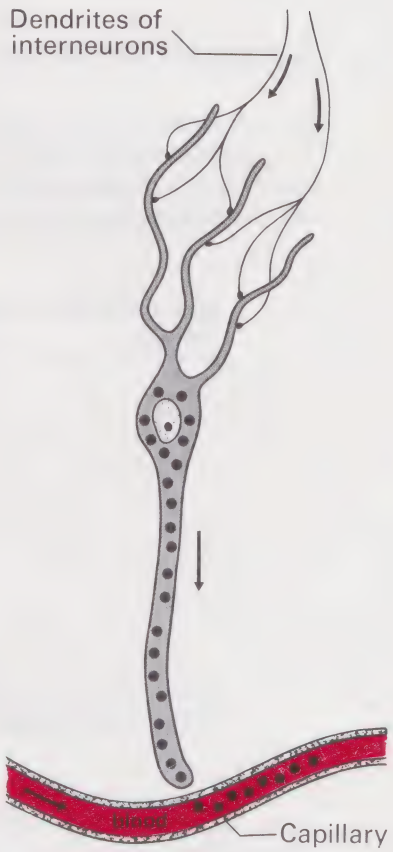



*Figure 24 Diagram of a neurosecretory cell. The neurosecretion is shown in grey and the blood in red. The arrows show the direction of movement.*

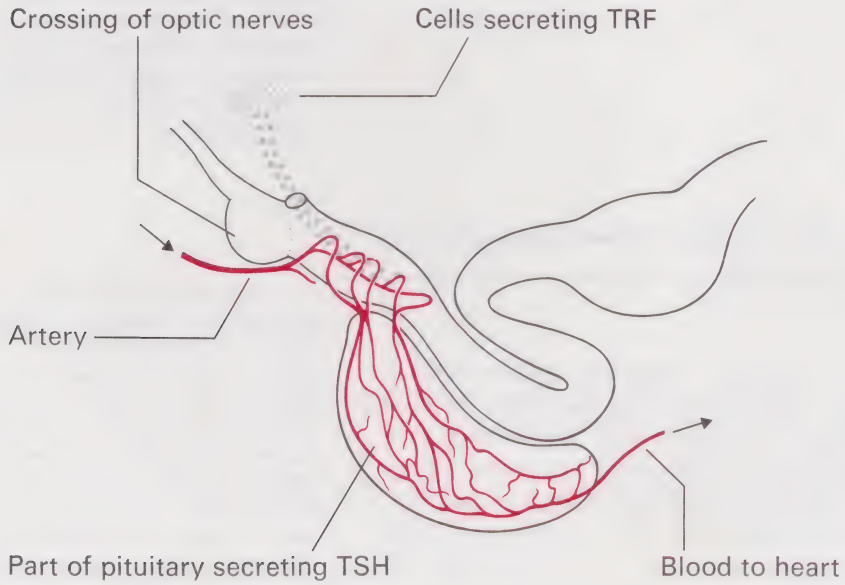



*Figure 25 Diagram to show how neurosecretions from the hypothalamus reach the pituitary gland through a portal vein. The neurosecretion is shown in grey and the blood supply in red. The arrows show the direction of movement.*

**Add this to your diagram of the flow sheet and feedback system for thyroxin (Fig. 22).**

You may wonder whether a change in the level of thyroxin in the blood affects the hypothalamus. There is evidence that a decrease in level may do so, particularly in cold weather, but that normally it does not. There is also evidence that TSH can inhibit the secretion of TRF.

**Add this to your diagram.**

**Compare your diagram with Figure 26.**

Here then is an elaborate control system working through hormones. There is a possibility of nervous control of the hypothalamus by other centres in the brain. But the control of the pituitary by the hypothalamus is through nerve cells producing neurosecretions that behave like hormones. It is probable that all the other hormones of the pituitary gland are either stimulated or inhibited by the hypothalamus through such neurosecretions (called 'releasing' or 'inhibiting factors').

Thus the master gland (the pituitary) is itself a slave to a part of the brain, the hypothalamus. But some of the pituitary hormones affect human moods and behaviour so that there is considerable feedback between the slave and the brain.

### 18.4.2 The control of the heart rate

The circulation of the blood, together with the substances transported in it, is clearly essential for the well-being of the cells of the body, so the heart's activity is essential for the functioning of all the organs of the body and for all activities of the body.

**Why should the rate of heart beat be variable and need feedback and control systems?**

The muscular activity of the heart uses up energy resources; the faster the rate of beat, the more energy is needed by the cardiac muscles. So it is an advantage if the heart rate can be adjusted to the minimum that is necessary to maintain a circulation of blood sufficient for the state of activity at any given time.

**Suggest states of activity which would require different minimum rates of circulation of the blood.**

A sleeping man, a man working at a desk and a man doing hard physical work are dissipating energy at very different rates. The glucose and oxygen required by their muscles circulate in the blood and the sleeping man's muscles will be using much less of these than the muscles of the labourer; the man at the desk will be using more than the sleeping man but much less than the labourer.

If the heart rate can be regulated so that the blood reaching the muscles brings sufficient glucose and oxygen for their activity at any time, but very little more, then the use of energy by the heart itself can be kept at a minimum; there is economy of energy use in the body. The actual output of blood from the human heart varies between about 5 litres per minute, in a sleeping man, and about 35 litres per minute, in a large robust man performing arduous work. The rate of heart beat varies between about 40 contractions per minute during sleep to a maximum of about 150 per minute during hard physical work. A man sitting at a desk has a rate of about 70 per minute.

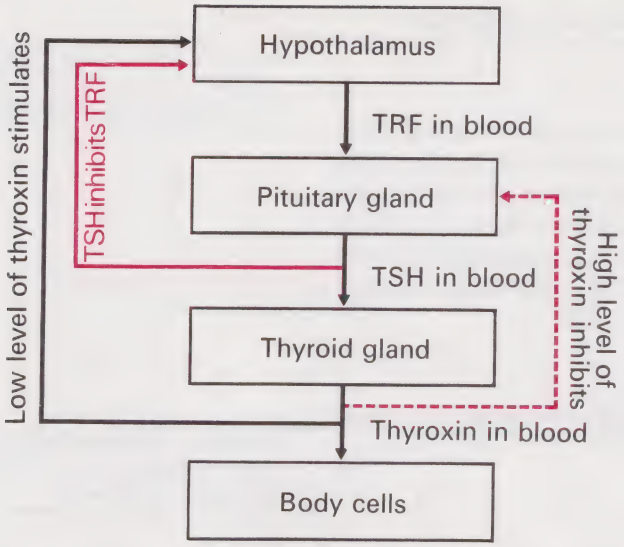



*Figure 26 Flow diagram to show the control of thyroxin reaching the body cells. The hypothalamus and two feedback loops have been added to the diagram in Figure 22.*

**You have already drawn a flow diagram showing how the rate of heart beat is regulated. What are the pacemakers?**

The SA node, with the AV node as a subsidiary pacemaker.

**Which part of the autonomic nervous system accelerates the heart beat?**

The sympathetic system.

**Which part slows down the heart beat?**

The parasympathetic system (vagus nerve).

**What hormone affects the heart and how?**

Adrenalin causes acceleration of the beat.

If you could not answer these questions, look back to Figure 21.

By balancing the input from these three systems, the rate of heart beat can be controlled at any required level, but there must be some system which adjusts the balance to the state of activity of the individual. There are two levels of control, both exerted through centres in the brain:

1 'Higher' centres determine whether a man is sleeping or awake, and whether a waking man is resting or taking exercise. The higher centres are connected through nerve tracts with 'lower' centres and thus control the latter.

2 There are two centres situated in that part of the brain which adjoins the spinal cord. One is called the cardio-accelerator centre and the other is called the cardio-inhibitor centre.

**Which of these acts on the heart through the sympathetic nervous system?**

The cardio-accelerator system.

**And the cardio-inhibitor system acts on the heart through which system?**

The parasympathetic system.

These two lower centres are close together anatomically. The higher centres control the balance between the two antagonistic lower centres, generally by altering the degree of activity of the inhibitory centre.

**When a man is very active, what changes probably occur in the blood?**

An active man is using more glucose and more oxygen than a resting man; he is producing more carbon dioxide.

The carbon dioxide is carried partly in solution in the blood. It is a weak acid so there are changes in the blood pH. If you do not remember what pH is, look back to Unit 9. In the main arteries carrying blood to the head there are receptor cells which respond to lowered pH and perhaps directly to carbon dioxide in solution. Impulses from these receptor cells stimulate the cardio-accelerator centre to greater activity. There is some evidence that the centre is itself sensitive to lowered blood pH.

**What will be the effect on the heart rate of increased carbon dioxide in the blood?**

Increase in the rate of beat and hence more rapid circulation of blood to the lungs and to the body.

**What will happen when the carbon dioxide concentration falls?**

The blood pH will rise and the receptors will be less stimulated, so the cardio-accelerator centre will be less stimulated.

When muscles are active, the arteries and capillaries supplying them are dilated and there is less resistance to the flow of blood. When these vessels are constricted, the resistance to blood flow increases and this causes an increase in pressure in the arteries close to the heart because the blood 'piles up' there. This leads to stretching of the walls of these great arteries, and stretch-receptor cells are stimulated. Impulses from these cells stimulate the cardio-inhibitor centre.

**What effect does this have?**

The heart rate is reduced so less blood is pumped round the body per minute.

Figure 27 is part of a flow diagram to show the control of the heart rate and the feedback system involved in this. Add arrows to complete the diagram (you may find it helpful to refer back to Figure 21).

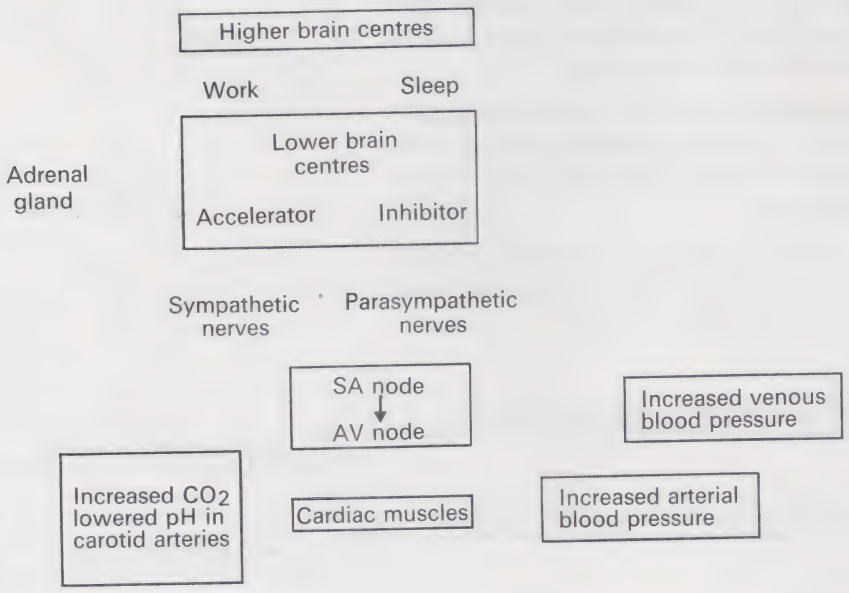



*Figure 27 Flow diagram, with connecting lines omitted, to show the control of the heart rate in man through centres in the brain.*

Figure 28 shows the completed diagram. Notice that it includes two loops in addition to those described above:

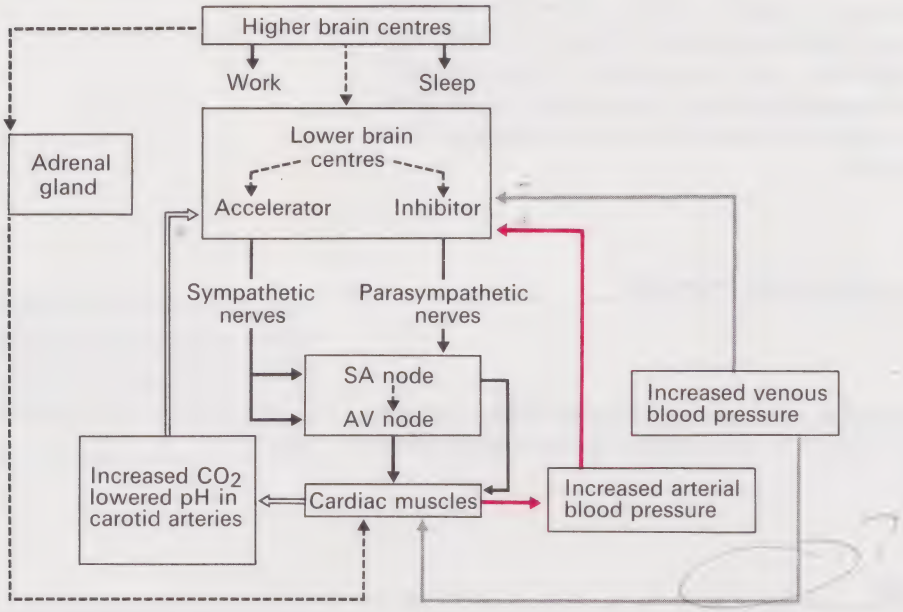



*Figure 28 Flow diagram to show the control of the heart rate in man through centres in the brain. The feedback system acting through arterial pressure is shown in red, that acting through venous pressure is shown as grey. See the text for explanation of differences between this diagram and Figure 27.*

1 The adrenal medulla is under the control of higher centres. Look back to your earlier flow diagram to see how the effect of adrenalin fits in.

**adrenal medulla**

2 When the muscles are active and much blood is flowing through, this blood returning through the great veins leads to increased, venous pressure. Stretch receptors in these veins produce impulses which lead to suppression of the cardio-inhibitor centre.

**What will be the effect of this?**

The balance will change so that the cardio-accelerator centre has more effect and the heart rate will increase. (This is the grey system in the diagram.)

You will remember that the heart has its own intrinsic rhythm; the two centres in the brain either quicken this or slow it, acting through the two divisions of the autonomic nervous system. The feedback information comes from sense cells in the great blood vessels responding to stretch or to lowered pH. The heart also reacts directly to various substances circulating in the blood, of which adrenalin is the most important.

**Your Home Experiment is to measure your pulse under various conditions, so you will be able to confirm some of the observations cited here for yourself.**

The control and feedback system for the heart is more complicated than that controlling the level of thyroxin in the blood. There are more types of cells involved: cardiac muscle; sensory and motor neurons of the autonomic system; neurons in the brain; and secretory cells of the adrenal gland. The interplay between the accelerating and inhibiting systems, each with its own feedback loops, allows a very fine adjustment of the heart rate to the changing needs of the body. An efficient circulation is combined with economic use of energy.

### 18.4.3 The control of body temperature

Man is able to maintain an almost constant temperature within the body. You will remember from Unit 15 that enzymes are affected by temperature. In man, the optimum temperature for most enzymes is approximately 37° C, which is the normal temperature in the blood supply to the head, as measured with a thermometer in the mouth or, more accurately, in the outer ear, close to the ear drum.

**Suggest a consequence of this constant temperature.**

Man can be active over a wide range of external temperatures ranging from arctic to tropical conditions. (Animals such as lizards without control of body temperature may be very sluggish in cold air.)

Perhaps the problems involved in maintaining a constant body temperature will seem more obvious if we look at household gadgets which maintain constant temperatures.

**Suggest one such gadget.**

Two are quite commonly found: a water heater and a refrigerator; a central heating system is another example.

**What special components related to temperature control do we find in these?**

Thermostats and either heaters or coolers.

**What does the thermostat do?**

In a heating system, the thermostat turns off the source of heat when the temperature rises above the 'set point', and switches it on again when the temperature falls. In a cooling system, the thermostat switches on the cooler when the temperature rises to the set point, and switches it off again when the temperature has been reduced below this point.

So the thermostat switches from one position to another at the set point, thus controlling a source of heat or cold. When very accurate control of temperature is required in special equipment, there may be both heaters and coolers controlled by the same thermostat. To run thermostatically controlled gadgets economically, they should be well insulated so that they lose (heaters) or gain (refrigerators) heat very slowly.

So we might expect to find in man the equivalents of thermostats, heaters, coolers and insulation. Let us tackle this list starting with the last one.

1 *What provides insulation for the human body?*

The main site for heat loss is through the skin. If you look at Figure 29, you will see that there is a layer of fat below it and that there are hairs trapping a layer of still air above it; both these insulate the skin, the fat being much more efficient than the somewhat sparse fur retained by man. Clothes, however, can act as very efficient insulators.

2 *What are the coolers in the human body?*

Heat is lost by radiation from the skin. The amount of heat lost depends on the state of the blood vessels there: if these are dilated, much blood flows through them, the skin looks pink or red and feels warm and much heat may be lost. When the very small arteries are constricted, the skin looks blue or white, and feels cold and the amount of heat radiated is greatly reduced. The flow of blood through the capillaries is controlled through the sympathetic nervous system acting on the small arteries. Some heat is also lost from the lungs while breathing; this loss is increased by panting.

The principal source of cooling, however, is the evaporation of sweat. This is a watery fluid produced by tubular glands which open on the surface of the skin. When sweat is poured out on to warm skin (blood

sweat glands

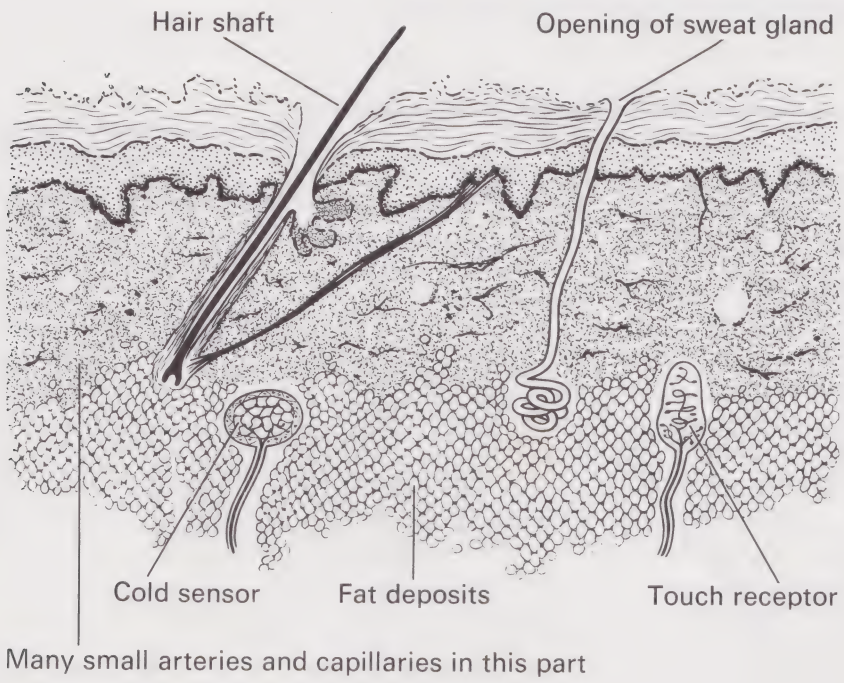



*Figure* 29 *Diagram of section cut through human skin.*

vessels dilated), then it evaporates. The heat required for this change in state from liquid to vapour is absorbed from the skin and the blood in the capillaries becomes cooled. This cool blood passes into the rest of the circulation so that the body is cooled. The sweat glands are controlled by the sympathetic nervous system.

### 3 *What are the heaters in the human body?*

Some heat production accompanies all the exothermic chemical reactions within the cells, so there is continuous heating within the living body. Muscular contractions also produce heat—you must have noticed the heating effect of running upstairs or for the bus.

### 4 *What is the thermostat?*

We can expand this question to make it more meaningful. What are the sensors that record the body temperature? What determines the 'set point'? How are the coolers and heaters 'switched on' and 'off'?

Our understanding of this system has developed very much in the last 15 years, largely as a result of the NASA† programme in the U.S.A., since temperature regulation is an important problem for man in space. There are separate 'thermostats' for heat and cold, so we will first consider the system which operates when the air temperature is above the set point of 37° C—that is, we will investigate man as a 'refrigerator'. The sensors which detect and respond to increases in the body temperature are in the brain, in a centre in the hypothalamus.

When the blood temperature in the head rises above 37° C, the sweat

glands begin to secrete. Figure 30 shows the observed relation between the temperature of the blood in the ear and heat loss through evaporation of sweat when the skin is warm. A loss equivalent to 10 per cent normal heat production can follow a rise of only 0.01° C in temperature. Sweating is not an efficient method of cooling when the atmosphere is hot and humid.

**Why?**

Because sweat does not evaporate if the air is already nearly saturated with water.

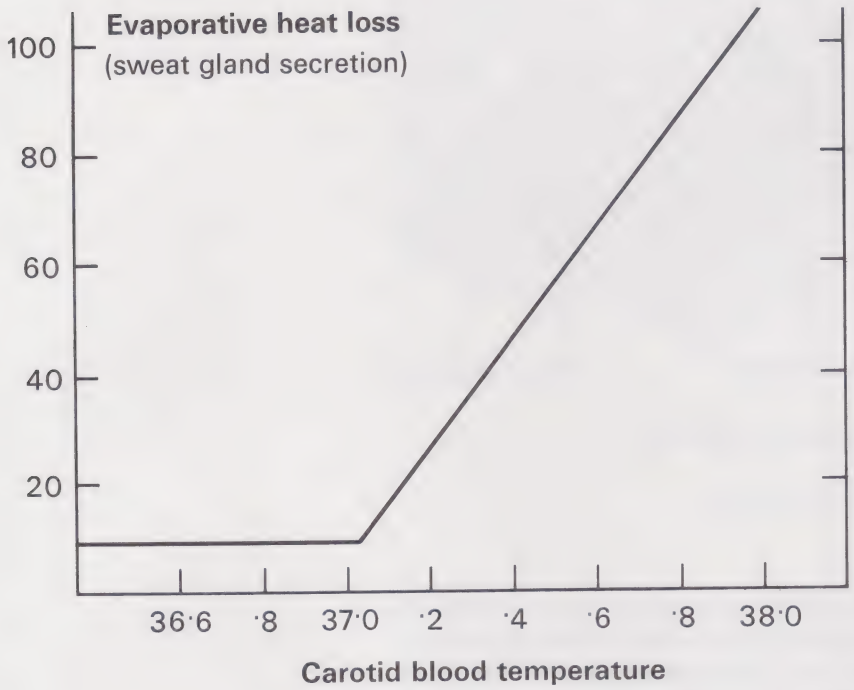



*Figure* 30 *Graph to show the relation between the loss of heat by evaporation of sweat from the skin and the temperature in the ear near the ear-drum of a naked man in a warm, dry atmosphere.*

How do men cope with this?

A fan can keep the air moving and so cause evaporation; in industrialized societies, men use air conditioning; they take baths or showers at frequent intervals; they may drink iced drinks. If a man cannot cool himself, he is likely to feel unwell or 'off colour'.

These behavioural reactions to heating of the blood show that there are connections between the heat sensors in the hypothalamus and 'higher centres' of the brain where conscious actions are initiated.

Now let us consider man as a heating system. Cold is detected through sensors in the skin. These begin to respond as the skin temperature falls below 37° C, but show the greatest activity at skin temperatures of about 20° C. The really important effect of stimulating the skin sensors by cooling the skin is to produce a conscious sensation of feeling cold, a response involving 'higher centres' of the brain. When men feel cold, they usually take prompt action to warm themselves.

**How do they do this?**

By increasing muscular activity (moving about, stamping, etc.), by putting on more clothes (increasing the amount of insulation), by turning on a source of heat, taking a hot bath, hot drinks and so on.

These behavioural responses generally occur sooner and are much more efficient in restoring body warmth than the physiological response of shivering.

**What happens when the carotid blood temperature rises above 37° C but the skin is cold?**

The sweat glands do not secrete.

Presumably there is inhibition of the centre controlling the sweat glands by impulses from somewhere in the system that responds to cold—the anatomical location of this inhibitory reaction is still unknown.

**What are the circumstances when this inhibition of sweating is likely to occur although the blood temperature is raised?**

When a man indulges in hard physical work in cold climate.

**This activity is transient and the reduction of heat loss while it is in progress is an economy—why?**

The surplus heat retained in the body means that less heat need be produced to maintain the normal body temperature when the exercise stops.

Figure 31 is part of a flow diagram to show the main components of the human temperature control system.

**Add arrows to complete the diagram.**

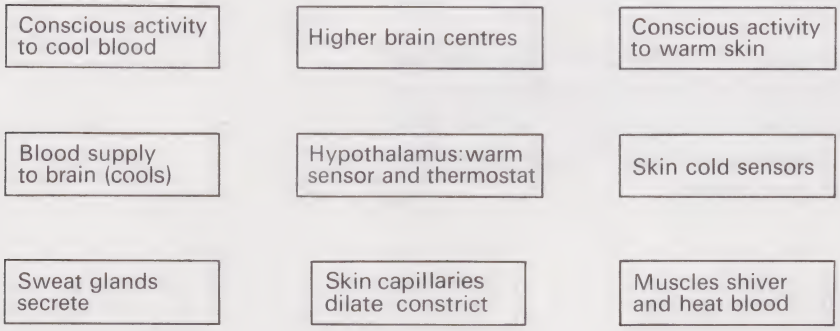



*Figure* 31 *Flow diagram, with connecting lines omitted, to show the control of body temperature in man.*

Figure 32 shows the completed flow diagram.

There are two control systems involved in the control of body temperature. Each has its own thermostat and feedback loop, but there are connections between them leading to efficient conservation of energy.

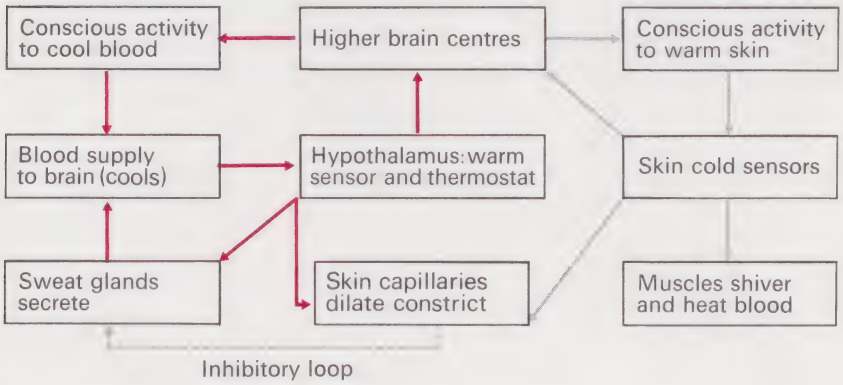



*Figure* 32 *Flow diagram to show the control of body temperature in man. The lines showing responses to hot conditions are shown in red, those showing responses to cold conditions are shown in grey.*

### 18.4.4 Summary of section 18.4

These three feedback systems in man are all vital for survival. We have chosen to study them because of the contrasts between them.

The control of thyroid secretion is almost entirely through chemical substances (hormones) circulating in the blood (although the distance travelled by TRF is very short). TRF and TSH are hormones with strictly limited target organs (the small groups of cells which secrete TSH and thyroxin respectively).

The control of the heart beat is mainly through the autonomic nervous system with two antagonistic centres in the brain just above the spinal cord. But the hormone adrenalin and some other substances circulating in the blood also affect the rate of contraction of cardiac muscle.

In the control of body temperature, also, there are two feedback systems involved. The most important response to a rise in body temperature (sweating) is mediated by the autonomic nervous system, but the most important response to cooling of the body is through 'higher centres' in the brain where the conscious sensation of cooling provokes behavioural responses leading to warming.

The level of circulating thyroxin and the rate of heart beat are not under conscious control and we are unaware of the first though occasionally very much aware of the second.

We are much more aware of body temperature and take active measures to keep ourselves 'comfortable' by adjusting external conditions so that our internal thermostat and heating and cooling devices are not over-stressed. We react consciously to external conditions through the activity of the brain and especially of its 'higher centres'.

*Now try* SAQs *11 to 13.*

## 18.5 Control Through the Brain

The reactions of all organisms to conditions in the outside world involve three sorts of activity.

**Can you name them?**

The obtaining of information, the processing of information, and action upon the basis of this information (see also Unit 1).

We normally think of these properties as applying only to complex animals with brains and elaborate nervous systems, but this is not the case. Certain sorts of action based on information presented to the organism from the outside world occur in simple organisms—as when *Paramoecium* avoids obstacles (TV programme). Similar but slower reactions can be observed in large plants, as when a climber twines round a stick.

These types of activity are very much more complicated in large animals. We have already referred to two key developments which have made possible the complex activity of 'higher animals'.

**Can you suggest what they are?**

The first is the presence of a network of nerve cells which can act as a rapid signalling device and enable one part of the animal to communicate with another part.

**Name a purely chemical signalling device which achieves the same effect.**

Hormones.

In a large body, hormones are effective only because there is an efficient blood system. Many hormones are rather general in their effects, increasing or decreasing the metabolic rate or specific activity of all cells of a particular kind, rather like the volume control on a radio.

**Give an example of such a hormone.**

Thyroxin.

Other hormones are much more specific in their effects with strictly limited targets.

**Give an example.**

TRF or TSH.

Nervous impulses, like these hormones with limited targets, are conveyed to rather few cells and their message is a specific one—for instance, instructions to a particular group of muscle cells to contract. This is like the tuning knob on the radio, selecting a particular programme. As animals increase in size and in the number of individual cells, of different types and degrees of specialization, so the need for this precise method of signalling becomes greater if there is to be efficient co-ordination.

The appearance of sense organs (refer back to Unit 1).

Eyes are one example of sense organs which can receive signals from a distance. Other examples are, of course, the ears (sound), the nose (smell), and the tongue (taste). Other sense organs respond to touch, temperature and pain, but these relate to signals derived largely from responses at the body surface. All these organs consist of special cells, or groups of cells, which are structurally specialized so that they respond to the signals.

### 18.5.1 Sense organs, effectors and the central nervous system

We will start with a simple situation—where the stimulus reaching the organism, and its response to it, are clear. If your finger is trapped in the hinge of a door, it is advantageous for your survival that information concerning the fact that the finger is being squeezed be assimilated and acted upon. The first step is the receipt of the information. This is the job of the sense organs. The final step must be the removal of the finger from the hinge. This is achieved by an appropriate set of muscular contractions, triggered by the information travelling down a nerve to the appropriate muscle. Between the sense organ and the muscle, the information has to be further processed, so as to select the appropriate muscular response, in this case the removal of the finger. How can this sequence be achieved?

For simple responses, all that is necessary is for the sense organ to acquire the information and transmit it to the relay cells, interneurons (18.2.4 and Fig. 10), within the spinal cord. These cells in their turn pass the information to the motor neurons whose axons are connected with the muscles; the message travels down the axon of the motor neuron to the muscle and the muscle contracts; the squeezed finger is removed. This process is shown in Figure 33.

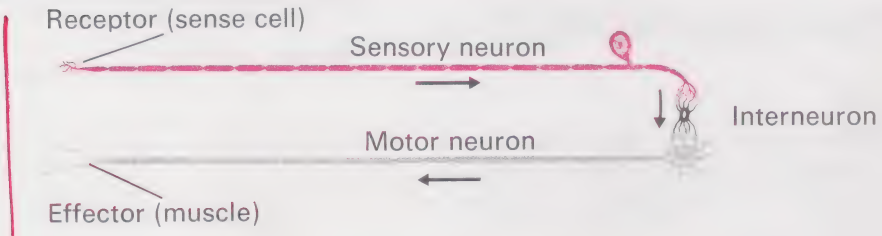



*Figure 33 Diagram of a simple reflex arc. The sensory neuron is coloured red, the interneuron is black and the motor neuron is grey. The arrows show the directions in which messages pass along the nerves.*

In such simple cases, the action appropriate to the information arriving at the sense receptor is fixed; the same stimulus always produces the same response. Such straightforward fixed responses are called reflexes, and the diagram we have drawn is sometimes described as a reflex arc. One of the best known examples of a single reflex is the knee jerk.

reflex arc

Figure 33 describes only the pathway between one receptor, one interneuron and one muscle cell. In reality, there will be many thousands of nerve cells in each receptor, and many thousands of interneurons and muscle cells.

For the reflex arc to work, it is necessary to translate the information presented at the surface of the body into the language of the nerves within it. Receptors, such as those for touch and pressure, are groups of modified nerve cells embedded in the tissue beneath the outer layer of the skin; we will not describe their structure here. The nerve axon rising from the receptor nerve cell must carry the message up to the spinal cord.

**How do nerve cells respond to stimulation?**

By an electrical charge which passes along the axon to the synapse (18.2.4).

The magnitude of this electrical charge is fixed (in most nerve cells it is about 60–90 millivolts). The speed at which it travels down the axon is also fixed and depends on the diameter of the axon (it is about 100 $ms^{-1}$ in human nerves to the leg).

**What other factors could vary so as to carry information down the nerve?**

The frequency of the impulse (the idea of frequency was discussed in Unit 2).

The frequency can vary from few to many hundreds of impulses per second passing along the nerve. It is in terms of changes in the frequency of 'firing' of the nerve that the information is conveyed. The receptors which respond to pressure (squeezing of the tip of the finger, for example) may fire at a rate of $x$ in response to a given pressure. Doubling the pressure may then increase cell firing rate (the rate at which impulses pass down the axon) by a factor of 2; quadrupling the pressure will increase the firing rate by a factor of 4 and so on up to the limit possible.

Thus the information about the degree of pressure being exerted at the skin is translated by the nerve cell into an alternative language, that of firing rate (the number of nerve impulses in a given time). For such nerves, a firing rate of such-and-such may be translated as meaning 'a pressure of so-and-so at a given point on the surface of the body'. The firing rate is thus a code or language system comparable, say, to the use of the Morse code to translate spoken or written words into a sequence of dots and dashes for wireless telegraphy.

**Name other codes of this sort.**

Braille for reading for the blind, magnetic tape on a tape recorder, the electronic signals of the television system are all examples.

All such codes must subsequently be decoded; the magnetic tape of a tape recorder, for instance, must be run through a playback head which will re-translate the message recorded in it in terms of the original sound which generated the recorded message in the first place. For the nervous system, all the cells within it speak more or less the same language, the message can be passed from the sense-receptor axon to the interneuron and on to the motor neuron, by way of the synapses, with only minor modifications. Thus a firing rate of $x$ in the incoming sensory axon might produce one of only $x/2$ in the interneuron and, perhaps, $2x$ in the motor neuron. In each case, the information is coded in the same general form in the different cells. The language is the same, though the accent may be different. Such a process of modification, which does not alter the content of the information, is called transcription, by contrast with the translation process we discussed earlier. (You met both these terms derived from information theory in Unit 17, in the rather different context of DNA and protein synthesis.) It is precisely because such terms are useful over widely different parts of biology that information theory and cybernetics have been helpful to contemporary biologists.

When the message arrives at the synapse between the motor neuron axon and the muscle, it must be interpreted by the muscle fibres as a set of instructions to contract. It is thus translated once more. Unlike the tape recorder, it is not translated into an exact copy of its original form, but into a specific response whose magnitude and form is dependent upon the original and is appropriate to it.

So far we have described a way in which a given stimulus to a sense receptor will always produce in the organism a given response. If this

were really the case, the organism would be a sort of robot or automaton. Yet this is not the case. When you put your clothes on in the morning, you are at first very conscious of their touch and feel upon the body; within a short time, however, this wears off. Similarly, when you sit down in a chair to read this text you will at first have felt the chair and your weight upon it. Within a few seconds or minutes, despite the fact that the same sense receptors are still in contact with the same object as before, you will have ceased to register an impression from them, except when you change your position. This is because the response by the receptors is not a constant one but is a response to a changing situation. Under constant conditions they cease to respond. This is an example of a phenomenon called *habituation* (see Unit 1).

habituation

There are other important ways in which the nervous system is not an automaton. Let us return to the reflex arc we quoted earlier. The connection between sense organ, spinal cord and muscle means that, when your finger is squeezed, you attempt to remove it. Suppose that someone pointed a revolver at your head and threatened to shoot you if you removed your finger. The probability is that you would leave your finger there. Yet the receptors in your finger would be signalling as before and would not yet be habituated, particularly if the pressure were increasing. What stops the signal from producing the standard response? To understand this, we must look again at the middle point of the arc, the interneuron cell. You may have wondered why it was there, and why the message did not simply go directly from sense receptor to motor neuron. You will remember (if not turn back to Fig. 11) that the spinal cord not only contains interneurons and motor neurons but also nerve tracts (bundles of nerve axons) which lead to and from the brain. These are axons connected with neurons in the brain and making synapses with interneurons of the spinal cord. The exact details of these tracts are very complex and only partially understood. But the result is that, as well as the message traversing the interneuron and triggering the motor neuron into action, the same message is also conveyed to the 'higher centres' in the brain. Generally, they will take no action upon this information. But if at the same time they receive other relevant information (e.g. from the eyes, the sight of the loaded revolver, from the ears, the sound of a threat to shoot if the finger is removed) it is possible for countermanding instructions to descend the cord and prevent the muscle contracting. We must therefore add to Figure 33, so that it looks like Figure 34.

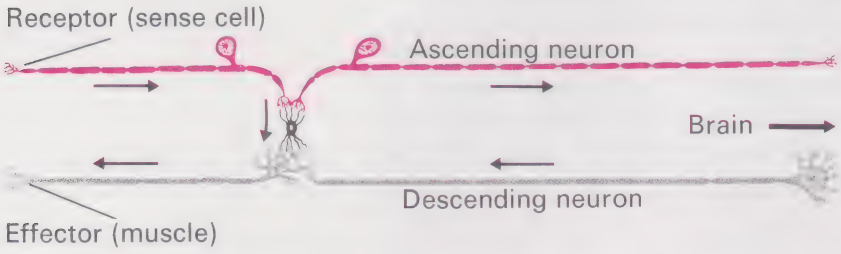



*Figure 34 Diagram to show how ascending and descending neurons of the spinal cord can affect a simple reflex arc. The sensory neuron and ascending neuron are red, the interneuron is black and the motor neuron and descending neuron are grey. The arrows show the directions in which messages pass along the nerves.*

At the cellular level, the countermand works as follows: the interneuron is triggered by impulses arriving at it from the synapse of the sense receptor axon; such a synapse, which excites the post-synaptic cell and causes it to 'fire' in its turn, is called an 'excitatory' synapse.

excitatory synapse

**Do you recall how the synapse functions? If not, see section 18.3.4.**

A chemical transmitter, such as acetylcholine, is released from the pre-synaptic side and alters the electrical properties of the cell membrane at the post-synaptic side, generating an impulse in the post-synaptic cell. The synapse from the descending axon from the brain contains a different type of chemical (probably an amino acid). When this is released it modifies the property of the postsynaptic cell membrane in the reverse direction; it makes it harder for the cell to fire. Such a synapse is called an 'inhibitory' synapse. In effect, it prevents or slows down the firing rate of the interneuron so that in its turn the latter fails to excite the motor neuron to instruct the muscle cell to contract. The final result will depend on the balance between the excitatory and the inhibitory effects.

inhibitory synapse

**Give examples of inhibition already mentioned.**

The centres controlling heart beat and some temperature responses.

## 18.5.2 Learning

The most important example of flexibility of the nervous system is the properties it displays when the animal learns. Some of these were discussed in Unit 1. A simple model of the learning properties of the nervous system is provided by the experiments of the Russian physiologist, Pavlov, in the early part of this century. Although the experiments relate to properties of the brain, not the spinal cord, the explanation is derived by analogy with the properties of the spinal reflex arc. Pavlov's best known experiment was one in which he presented food to a hungry dog. The dog, on seeing the food, would salivate. As the food was presented, a bell was rung. After several presentations of bell and food together, the bell was rung alone without the food being presented. The dog salivated as if it had seen the food. Pavlov interpreted this to mean that the dog now associated 'food' and 'bell'—it had learned that the sound of the bell showed that food would subsequently be presented. Pavlov described this association in language drawn from the example of the reflex arc. Salivation was equivalent to the reflex following the presentation of food. Association of the sound of the bell with the food results in a modification of the nervous pathways of the brain so as to produce a new 'reflex arc' in which the sound of the bell now results in salivation (Fig. 35).

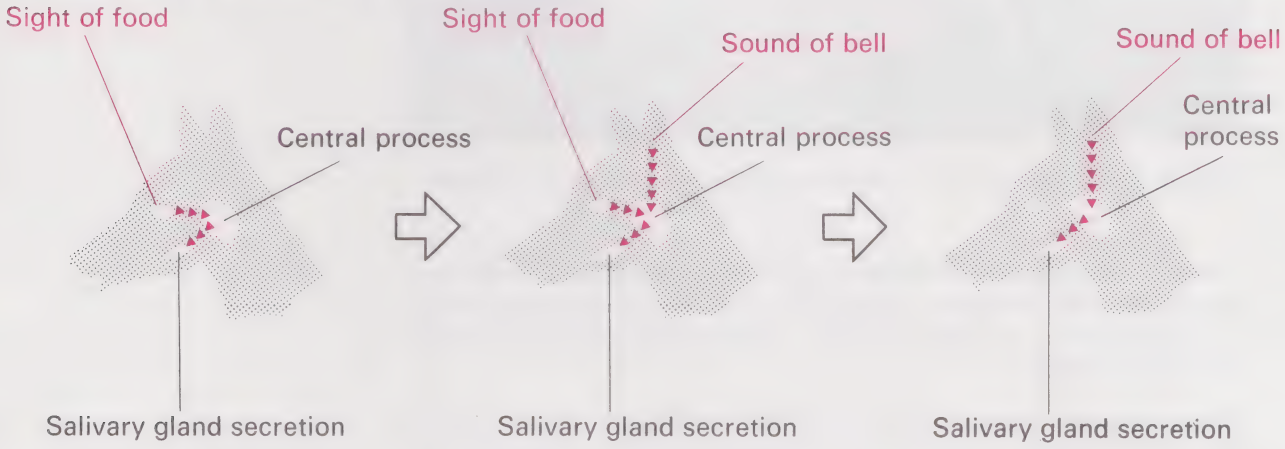



*Figure 35 Diagram to illustrate Pavlov's experiments with dogs. The nervous pathways are shown in red. See text for full explanation.*

This pathway is much more complex than the simple reflex arc, since it involves sense receptors which are not connected by a single interneuron to the motor nerves which cause the salivary glands to secrete. Within the brain the numbers of intervening 'interneurons' between sensory input and motor output may be very large. Such pathways are called 'multisynaptic'

in contrast with the 'monosynaptic' pathways of the simple reflex. To give some idea of their complexity, the 'higher centres' of the human brain contain $10^{10}$ nerve cells. Each cell may make up to $10^4$ synapses with neighbouring ones. Many of these cells are in an almost constant state of nervous activity, firing either as a result of varying sensory information, or apparently spontaneously; this is the so-called endogenous activity of the brain. This electrical activity is so intense that it can be detected through the skull, if recording electrodes are placed upon the scalp. When this is done, a characteristic pattern of brain waves emerges as shown, for example, in Figure 36.


*Figure* 36 *Diagram of an EEG record (electroencephalogram) of the alpha rhythm from the brain of a normal man with eyes open (red background) and eyes shut (grey background).*

The record is called the electroencephalogram, and the apparatus used to obtain it is shown in use in Figure 37.

*Figure* 37 *Photograph showing an electroencephalograph in use on a patient in a hospital.*

Electroencephalograms are sometimes a useful diagnostic tool for doctors looking for brain illnesses, though little is known yet of how to relate back the activities recorded to an exact understanding of the behaviour of the cells in the brain.

The sensory input to the brain involves more varied types of information than that reaching the spinal cord. Receptors in the skin are fired by direct pressure, touch, pain.

**What stimulates the receptors of the eye, as when the dog sees the food in Pavlov's experiment?**

Light waves.

Possible types of information are provided by the wavelength of the light (i.e. its colour), its intensity, or the rate of change of intensity (e.g. how

fast it is getting dark or light). The light sensitive cells of the retina of the eye (Unit 1) can respond to wavelength and to intensity; information concerning rate of change is processed not by the retina but by the cells of the visual cortex of the brain to which, by way of several synaptic steps, the retinal cells are connected. In a similar way, sound waves are translated into nervous information by the ears and auditory system. The 'cerebral cortex' contains most of the 'higher centres' to which we have referred in earlier sections; the visual and auditory cortex are part of it (Fig. 23).

Thus the pathways which Pavlov's experiment assumed: of sight of food→salivation (the original reflex); and the new pathway of sound of bell→salivation, which the conditioning process established, are in reality simple abstractions of complex events which occur within the brain. Indeed, it is very doubtful whether it is possible to account for much of brain functioning in terms of the formation of reflex pathways in the way that Pavlov hypothesized. Nonetheless, his experiments opened the way to much more sophisticated research on learning and the functioning of the central nervous system because they provided a theory which suggested experimental tests.

It is generally accepted today that when learning takes place, some permanent change, which enables this new information to be stored, must occur within nerve cells of the brain. The new information is, of course, a memory and in its stored form it is called a 'memory trace'. One hypothesis is that this permanent modification involves some change in the biochemistry and structure of the synapses between nerve cells within the brain. Such changes would provide the new or different pathways required. Certain drugs interfere with the transmission of information across a synapse by reacting with the chemical transmitter substances or with the enzyme systems that produce or destroy them. These drugs can have profound effects on behaviour patterns and on learning ability. Hallucinogenic drugs such as LSD (Lysergic acid diethylamide) and many of the tranquillizers or antidepressants in common medical use are believed to act in this way.

### 18.5.3 Brain and computers

*Neurobiology*, the study of the brain and its behaviour, is one of the fastest growing of the biological sciences today. Electrical recording devices can be inserted even into single cells within the brain, the electron microscope can be used for fine study of the synapse and other brain structures, and there are biochemical techniques for detecting changes in the brain of experimental animals during learning. All these have contributed to an increasing understanding of the relationship between brain structure and function, and of the control processes which govern the relationships between the brain and the rest of the body and between both and behaviour. People often ask to what extent the operation of an animal and a human brain is predictable and manipulable; to what extent the brain is like a computer.

We can describe the operation of the brain in terms of information theory, which has also been used in the design of computers, and quite a few research workers today believe that it would be possible to understand more of the mechanism of the brain if we could make mathematical models of the interactions of individual nerve cells. This is a theme that will be explored in the radio programme associated with this Unit. Our general conclusions may be stated here: the comparison with computers is a valuable analogy of the sort that is useful in stimulating scientific research and understanding, but the most powerful computers yet built are not really capable of showing the 'intelligence' of a worm, still less of a human being. Nonetheless, if we understand computers, we may learn more

about the brain, and by studying the brain we may well discover how to build better computers.

*Now attempt* SAQs *14 and 15, which refer to this section.*

**Conclusion**

Just as cells can be broken down into their component organelles, so multicellular organisms can be broken down into organs, tissues and cells. As with the components of cells, these components of living organisms must be co-ordinated and their activities regulated to produce the integrated independent organism. Complicated organisms can survive only if there is internal homeostasis. It is essential that the internal environment should remain constant in certain features, as with the body temperature of man. It is also essential that the organism should respond effectively to changes in the external environment. Some of these responses involve adjustments of the internal equilibrium, as when a frightened man secretes adrenalin and runs away with his heart beating fast.

Appropriate behaviour to external stimuli depends on sense organs detecting these stimuli and components of the nervous system interacting so that the organism moves or does not move to give the most effective response. Some responses are almost automatic reflexes. Some physiologists, such as Pavlov, have interpreted the whole of behaviour in terms of reflexes modified through repetition and association with different stimuli. Study of the brain has revealed some ways in which learning may be described, but we are still far from a complete explanation.

*Now try* SAQs *16 to 20, which refer to the whole Unit.*

## Summary

Living units that can survive independently under natural conditions are called organisms. Many organisms consist of one cell only, but these are all small, being limited in size by the surface area to volume ratio and the nucleo-cytoplasmic ratio (18.1). Appendix 2 (Black) describes some common unicellular organisms and related forms living in fresh waters.

Man is a large, multicellular organism, composed of specialized cells that are associated into tissues that are in turn associated into organs and organ systems (18.2.1). The vital activities are shared among these systems (18.2.2). Three systems are studied in greater detail: the blood vascular system (18.2.3); the nervous system (18.2.4); and the endocrine system (18.2.5).

Homeostasis is essential for the survival of large multicellular organisms (18.3.1). Co-ordination of the activities of cells within an organism may be achieved: by cells acting directly on other cells, as in the heart musculature (18.3.2); through the nervous system, as with the autonomic nerves supplying the heart (18.3.3); through the circulation of hormones in the blood (18.3.4). Some hormones affect many body cells; some vary greatly in level, as does adrenalin; others stay at an almost constant level, as does thyroxin. Some hormones have very limited target organs, as does TSH. The control of physiological processes can be expressed using flow diagrams (18.3.5).

Homeostasis depends on the efficient operation of feedback mechanisms adjusting the rate of physiological processes. Feedback may depend on circulating hormones (18.4.1), or on sense receptors within the body of which we are not conscious (18.4.2), or on sense receptors promoting conscious activity as well as unconscious regulation (18.4.3). Centres in the brain are involved in many regulatory and feedback processes.

Survival requires appropriate responses of the organism to external situations (18.5). These responses may be reflexes (18.5.1), but brain activity is usually involved. The activity of sense organs and the brain can be described in terms of information theory (18.5.2), as can the action of computers (18.5.3).

# Appendix 1



## Glossary

ANAEROBICALLY Living and metabolizing without oxygen.

ANATOMY The science of the structure of animal and plant bodies.

ELECTROCARDIOGRAPH or ELECTROCARDIOGRAM The termination 'graph' means 'instrument that marks, or records' whereas the termination 'gram' means 'something written'—hence the electrocardiograph is the machine that records electrical changes of the heart and the electrocardiogram is the record produced by the machine.

ELECTROENCEPHALOGRAPH or ELECTROENCEPHALOGRAM As for the definition above, the former is the machine that records the brainwaves and the latter is the record produced by the machine.

HABITAT The kind of locality in which a plant or animal naturally grows or lives.

KIDNEY TUBULES The structures within the kidney through which urine is secreted.

MONITOR A device that regulates the volume or intensity.

NASA National Aeronautics and Space Administration, the body that controls the space programme in the U.S.A.

PHYSIOLOGY The science of the normal functions of living plants and animals.

STETHOSCOPE An instrument for examining the chest or other part, conveying the sound of internal organs to the ear of the observer.

SUBSTRATUM 'An under-layer of any material substance' used in biology as a term meaning the bottom of lakes, rivers and the sea.

## Appendix 2 (Black)

### Unicellular Organisms and Simple Colonies

Many different types of organisms consist of single cells only. Some of these are shown in this Unit's TV programme, and models of three of them are illustrated in the broadcast notes. If you follow the instructions in Appendix 3 (Black) and collect water and debris from ponds and streams, you should find many other single-celled organisms and simple colonies. Some of these are shown in the colour transparencies—film strips 18(a) and 18(b); many others are illustrated in the line drawings of Figures 38 to 45. You can use these pictures to try to identify your collections.

DO NOT ATTEMPT TO REMEMBER THE NAMES OF THE ORGANISMS—they are given here for ease of reference. DO NOT ATTEMPT TO REMEMBER THE DETAILS OF THE STRUCTURE OF THE ORGANISMS—they are given here because they are useful in identification.

The intention of this Appendix is to present a brief survey of the different types of single-celled organisms that live in freshwaters in the British Isles and thus to illustrate our statement in section 18.0 that organisms of great diversity exist with bodies equivalent to single cells. In view of our comments in section 18.1, you should take note of the actual sizes attained by these organisms—you can work these out from the magnifications given for the illustrations.

1 *Viruses* You met viruses in Unit 17—are these living organisms? They can reproduce themselves—provided that they are inside living cells—but they cannot grow or reproduce apart from their host cells. Thus they are on the borderline between truly live organisms and macro-molecules. They have no cellular organelles comparable with those of larger organisms.

2 *Bacteria* These can live independently and grow and reproduce without the assistance of any other living cells—so there is no doubt that they are living organisms. They are difficult to study under the light microscope because of their small size. They are very common in freshwaters, but you will not be able to observe them yourselves so we shall say little about them here. Under the EM (electron microscope) bacterial cells show the following features.

   (a) There is usually a rigid cell wall with a cell membrane inside it.

   (b) This cell membrane is sometimes folded inwards; the respiratory enzymes are always located immediately under it.

   (c) The cytoplasm has no membranes within it but there is usually a clear area in the centre of the cell with much DNA (or RNA) there.

   (d) Outside this clear area, the cytoplasm contains many small ribosomes.

**Name two structures that you expect to find in cells that are not mentioned above, i.e. absent in bacteria?**

Nucleus and mitochondrion.

The central clear area has some of the properties of the nucleus and the folded cell membrane has some of the properties of mitochondria.

Some bacteria perform photosynthesis and contain 'bacterial chlorophyll' on small granules. Occasionally these granules join to form simple lamellae, but they are never separated from the rest of the cytoplasm by membranes.

**Is this the same as the chloroplasts of higher plants?**

No, it is simpler.

Bacteria are very interesting because they can have many different metabolic pathways. They live in a diversity of habitats.† Some of them are very important as 'decomposers' of dead organisms (we shall refer to them again in Unit 20); others are parasites causing unpleasant diseases in man and in many other animals and plants.

*Protistans, algae and protozoans*

Multicellular organisms are generally recognizable as either 'animals' or 'plants'. It is usually considered inappropriate to try to classify viruses and bacteria as either plants or animals, but the larger unicellular organisms are often claimed for study either by botanists or by zoologists. Those studied by botanists are called ALGAE and those studied by zoologists are called PROTOZOA. Some organisms are studied in both disciplines.

**Suggest possible differences between algae and protozoans.**

You might expect algae to perform photosynthesis and therefore to be green, whereas protozoans would not be green. You might also expect protozoans to move about in search of food, whereas algae would be non-motile. Using these criteria, you would be able to classify some organisms very clearly as algae (plants) and others as protozoans (animals); but there are many unicellular organisms that are both green and motile, such as *Euglena* (shown in the TV programme), and there are groups of organisms that resemble each other very closely in structure, except that some are green and others are colourless. It is perhaps not surprising that many organisms are classified both as algae and as protozoans—usually in different books! The term PROTISTA (protistans) includes all protozoans and all unicellular algae and all the intermediate or overlapping groups—so we shall use it here and later in Unit 21.

When protistans reach a certain size, they divide. The two 'daughter cells' may separate or they may remain together as chains (or filaments) or masses—these are simple colonies. Within each of these simple colonies, all the cells are usually capable of carrying out all the vital activities, including reproduction by division. Green protistans form filaments much more frequently than do colourless protistans. In fact, there is a gradation from solitary green protistans through filaments to quite large and clearly multicellular plants, the seaweeds. All these are included by botanists in a single group—the algae. It would not be logical to call seaweeds 'protistans'; filamentous algae are also usually excluded from this term—consequently we shall use the term 'alga' here for certain groups that include filamentous as well as solitary organisms.

3 *Blue-green algae* (Figs. 38 and film strip 18(a): 6 and 7). These are generally filamentous, but some are solitary and some form irregular

# Appendix 2

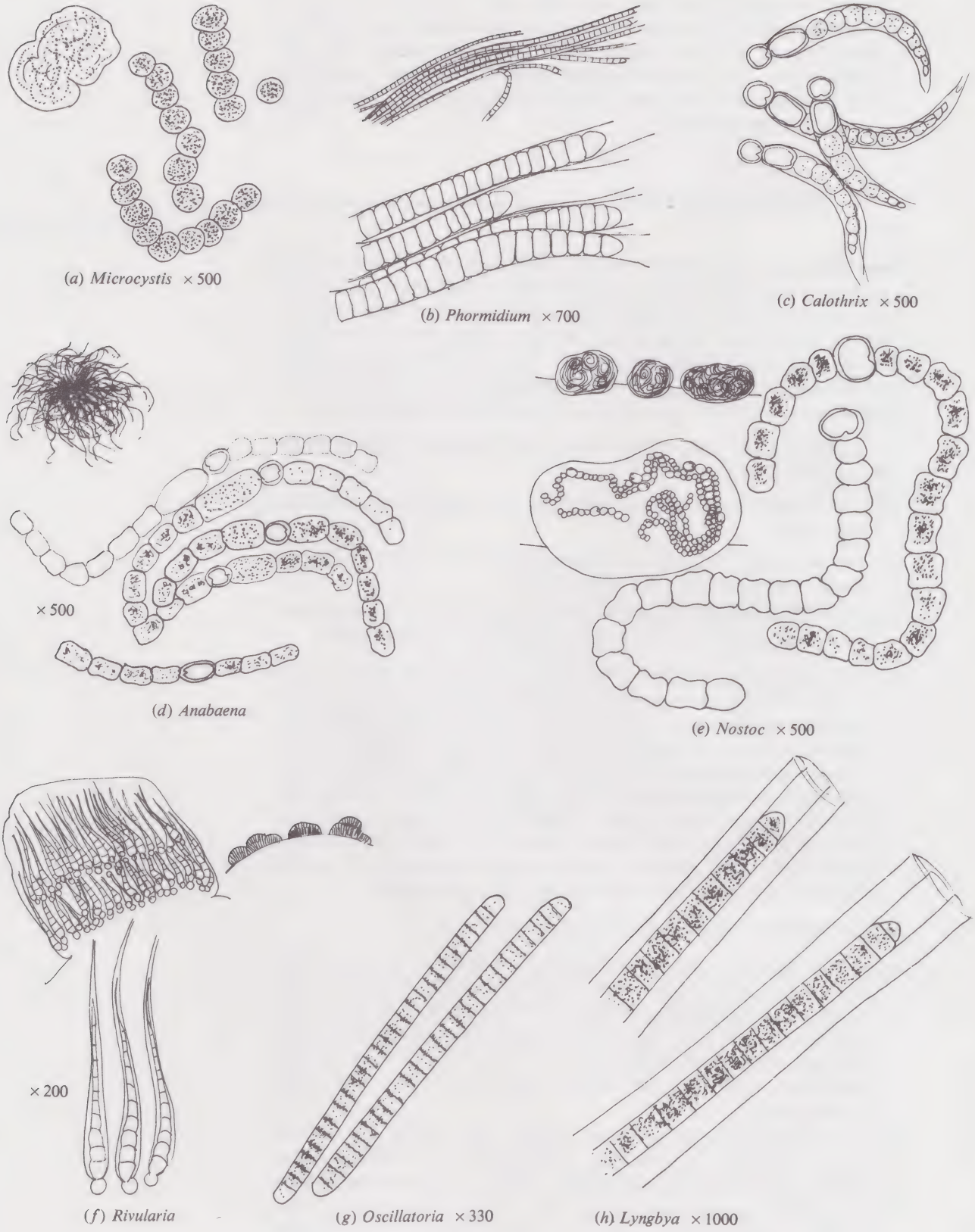



*Figure* 38 *Drawings of living blue-green algae as seen under the microscope.* All these are coloured forms.

masses or spherical colonies. The cells have a distinct wall and a mucilaginous sheath outside this—which makes them stick together. There appear to be two regions inside the cell membrane: an outer coloured area, with the photosynthetic pigment arranged on lamellae, and an inner colourless area. There are no definite chloroplasts, or nuclei, or mitochondria.

**Of what does this remind you?**

Bacteria.

Blue-green algae have much in common with bacteria and it is possible that these two groups are more closely related to each other than to any other organisms. The blue-green algal cells are larger than those of bacteria, but still very small. Many blue-green algae float in still water; they are common in lowland reservoirs. They may multiply so rapidly that the water turns a livid green; this 'water bloom' can be a considerable nuisance to water supply undertakers because the cells clog the filters.

All groups of organisms *except* bacteria and blue-green algae show the following features.

(a) The resting nucleus is separated from the cytoplasm by a nuclear membrane.

(b) The respiratory enzymes are separated from the cytoplasm and are found inside organelles, the mitochondria.

(c) When photosynthetic pigments are present, they are separated from the cytoplasm and are found inside organelles, the chloroplasts.

4 *Green algae* (Figs. 39, 40, 41, 42 and 44 and film strip 18(a): 1, 2, 4, 7 and 8). This large group includes a wide range of forms—solitary, colonial and filamentous. It is of special interest since it is probable that the ancestors of larger plants were of this type. The cells may have a single or many nuclei; there may be one or many chloroplasts and they may have distinctive shapes. The cell membrane lies within a rigid wall of cellulose; there is often a large fluid-filled vacuole inside the cell and the motile forms usually have two or four cilia of equal length. Most green algae live in freshwaters, but some live in the soil or form a greenish scum on tree-trunks; a few are marine.

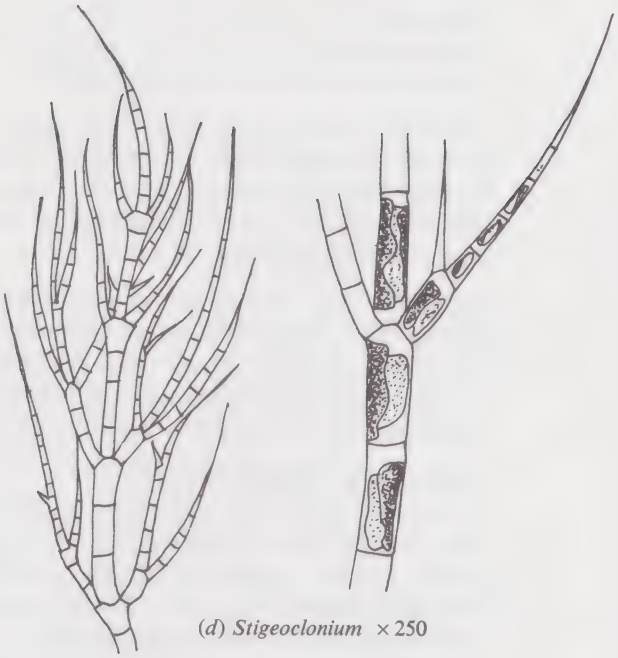
It is convenient to divide them into three groups.

(a) *Filamentous green algae* (Figs. 39 and 40 and film strip 18(a): 7 and 8). The principal features, which vary from one to another, are: the shape of the chloroplasts; whether the filaments branch or not; and whether the cells in the branches are smaller than those in the main filament. These filamentous forms are on the borderline between individuals associated into colonies and the existence of a multicellular body.

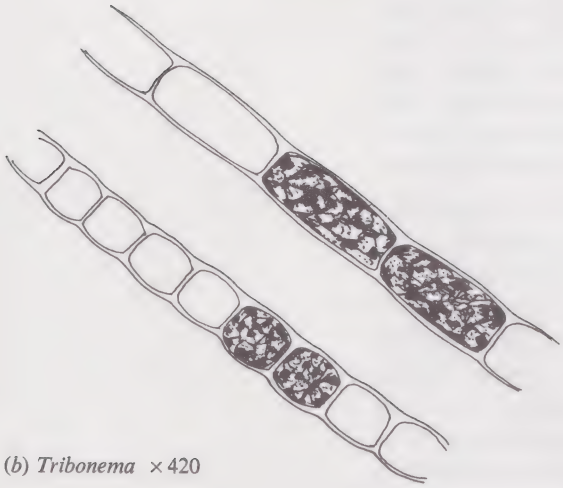
(b) *Non-motile unicellular or simple colonial forms* (Figs. 41, 42 and 44 and film strip 18(a): 4). One widespread group of these is called the 'desmids'—in these, the cell wall is often complicated and bizarre in shape; it is in two parts that are mirror images of each other. There is often a constriction between these two 'semi-cells'. Some desmids produce much mucilage and perhaps 'glide' along such secretions. Many float in freshwaters, others are attached to plants, stones or the surface of mud by their mucilage. Occasionally the cells form short chains.

# Appendix 2


(*a*) *Batrachospermum*



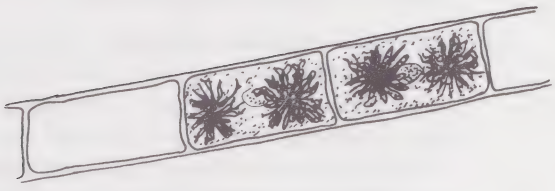
(*d*) *Stigeoclonium* ×250



(*b*) *Tribonema* ×420

(*e*) *Microspora* ×250

(*c*) *Vaucheria* ×125



(*f*) *Zygnema* ×750

*Figure* 39 *Drawings of living filaments of red, yellow-green and green algae, as seen under the microscope.* All these are coloured forms.

(c) *Small motile forms, either solitary or living in colonies* (Fig. 44 and film strip 18(a): 1 and 2). These have two or four cilia. The largest and most complicated of the colonies is *Volvox*. A few of the solitary forms lack chloroplasts (and so are colourless).

5 *Yellow-green algae* (Fig. 39 (b) and (c)). These are single-celled or filamentous forms which are separated from the green algae because the main storage product is not starch but oil or fat and because their cilia, when present, are of unequal length. They look very like the green algae, but there are fewer of them.

6 *Red algae* (Fig. 39 (a)). These are named 'red' because the green chlorophyll is masked by purple pigments. Most of them live in the sea and you would recognize them as red seaweeds. *Batrachospermum* is quite common as reddish-green masses on stones in calcareous, unpolluted rivers. Compare it with the other filamentous algae.

7 *Diatoms* (Fig. 43 and film strip 18(a): 3). These are very numerous in the sea as well as in freshwaters, as floating or as attached forms; some live in the soil. There may be few or many chloroplasts; there is usually a large vacuole and a single nucleus; the cell wall contains silica and consists of two parts which fit together like a box and its lid. The silica varies in thickness, producing a complex series of markings; the siliceous cell walls can survive after the death of the cells—these diatom cases have delighted many microscopists by their intricacy and beauty. Diatoms produce mucilage and sometimes individuals stick together in groups or chains. Rapid multiplication sometimes leads to bright green 'water blooms' of diatoms in reservoirs or parts of the sea.

8 *Dinoflagellates* (film strip 18(a): 5). Most of these are so small that you will not observe them, but they are often very numerous in the upper waters of the sea, where more than $10^6$ individuals may occur per litre. The cell shown in the transparency has a very definite shape—this is due to the presence of plates of cellulose. Most dinoflagellates are rounded, not pointed; they typically have two unequal cilia in grooves between the cellulose plates. Some occur as masses or as short filaments; some lack chlorophyll and feed by engulfing other organisms. Here, then, within one group are some plant-like and some animal-like organisms—a justification for our use of the term Protista to include these forms.

9 *Euglenoid protistans* (film strip 18(b): 9). *Euglena* was shown in the TV programme and it is illustrated in the broadcast notes. It differs from typical plant cells because it moves and it also lacks cellulose. Related forms lack chlorophyll and live heterotrophically (Unit 21).

10 *Amoeboid protistans* (film strip 18(b): 10 and 11). *Amoeba*, shown in the TV programme and illustrated in the broadcast notes, is chiefly remarkable for its apparent absence of complex organelles, but it has a nucleus and one contractile vacuole. It moves and feeds by changing its body shape, producing pseudopodia. It is most common in pools and streams where there are gentle water movements and it often lives on the underside of leaves of aquatic plants. It has relations, such as *Arcella* (film strip 18(b): 11), which have cases from which the pseudopodia project. Some of these related forms, the groups called Foraminifera and Radiolaria, are very common in the sea; they have skeletons of silica or calcium carbonate, some of which are elaborate and beautiful when observed under the microscope. The dead skeletons accumulate as oozes on parts of the ocean floors.

# Appendix 2

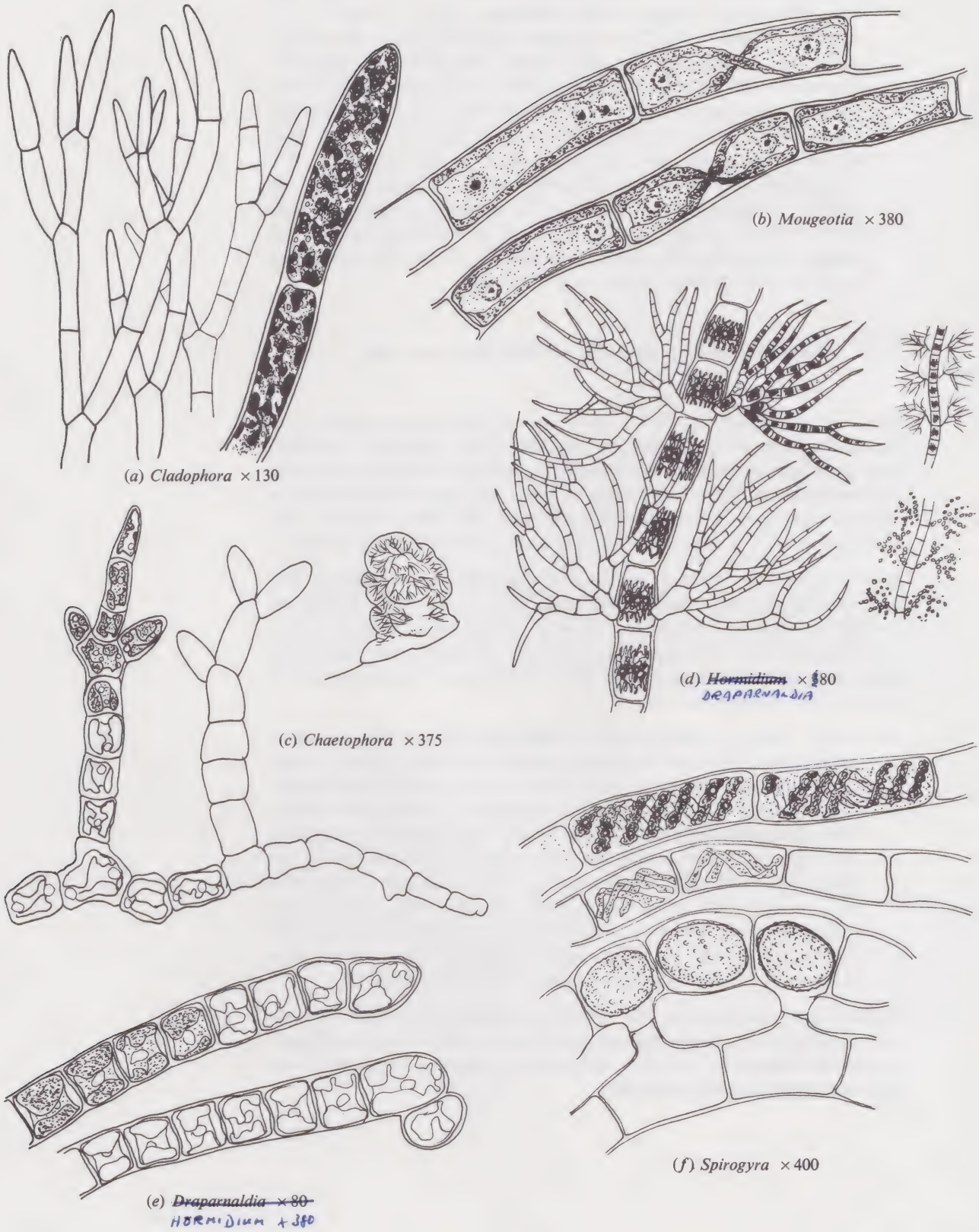



*Figure 40 Drawings of living filaments of green algae as seen under the microscope.* All these are coloured forms.

11 *Ciliate protistans* (Fig. 44 and film strip 18(b): 12, 13, 14 and 15). This large group includes many freshwater forms of which *Paramoecium*, shown in the TV programme and illustrated in the broadcast notes, is probably the best known. All have cilia, generally concerned with creating water currents and bringing food to the gullet and also with movement. All ciliates have two types of nucleus and usually at least one contractile vacuole. Some are stalked, such as *Vorticella*, others have specialized cilia, as you saw in the TV programme. The free-living freshwater ciliates include a great diversity of forms—but you should look carefully at organisms that you identify as 'ciliates', because you may be observing multicellular animals called *Rotifers* ('wheel animalcules' of the old naturalists). Look at Figure 42 and at film strip 18(b): 16.

**Suggest how you might distinguish between a ciliate and a rotifer.**

The rotifers have organs inside their bodies—if you watch carefully, you should see parts of the gut moving, including 'jaws' inside the 'stomach'. The outer layer of the body is a non-living secretion with joints that make it possible for the animal to change its length, but you should be able to see cells making up the organs inside the body. The cilia of Rotifers, like those of ciliates, produce water currents during swimming and feeding.

In view of the statements in section 18.1 about size and complexity, you may wonder why some multicellular organisms are no larger than some unicellular organisms which live in very similar ways. This is a very interesting problem. Unfortunately we cannot discuss it here, because to appreciate the arguments you require much more knowledge about animals than you have at present.

12 *Fungi* This is another group of organisms of which you should be aware when you look at small organisms in water. Fungi are all colourless (or, rather, not green); they usually obtain their food by breaking down the tissues of other organisms, generally after death. Some fungi are single cells—these are the *yeasts*, referred to in Unit 15; sometimes their cells form short chains. The other fungi are filamentous, either with one nucleus in each cell or with many nuclei and few cell walls along the filament. Aquatic fungi usually have simple filaments, but some terrestrial fungi develop complex reproductive bodies, the toadstools and mushrooms. You will examine photographs of some fungal reproductive bodies in Unit 19.

Aquatic fungi look rather like filamentous algae except that they are colourless instead of green. You are quite likely to collect them in stagnant or polluted water and, of course, they can be a nuisance in aquaria when they attack fish and other animals.

# Appendix 2

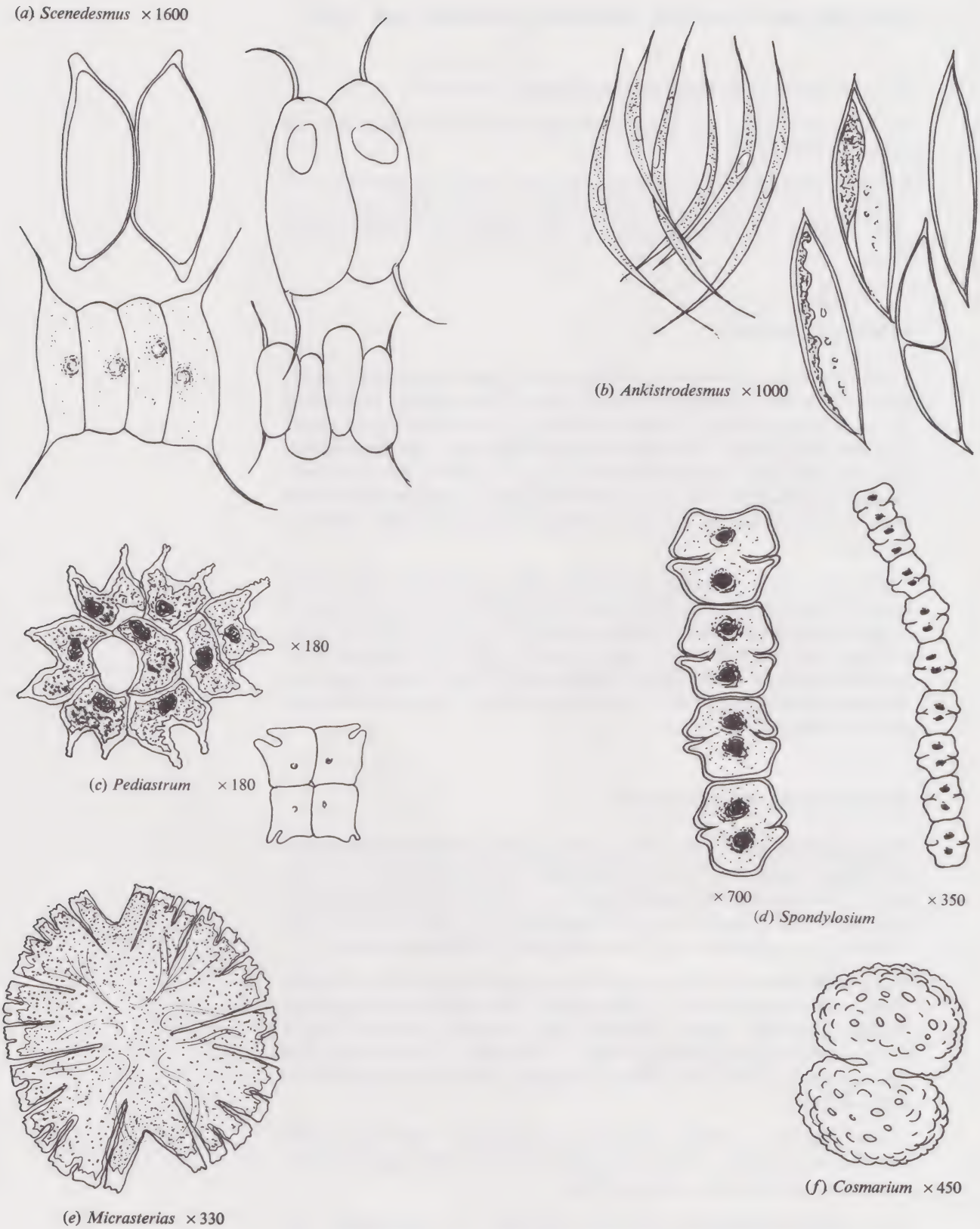



*Figure 41 Drawings of living colonies and individuals of non-motile green algae as seen under the microscope.* All these are coloured forms.

# Appendix 3



## Collecting and Examining Freshwater Protistans and Algae

(Home Experiment for those with the time and inclination.)

*Aim* To see some of the variety of living organisms of microscopic size present in freshwater.

Although most relevant to this Unit's main text study, this practical work can be done at any time during the summer—or indeed at any time of year—as and when you have spare time and the inclination to use your microscope.

### Collection of material

The best sources for freshwater Protista and Algae are ponds or slowly flowing streams with plenty of rooted plants. Water slightly polluted by sewage or farmyard waste is often interesting. If you maintain an aquarium at home, this is often a rich source of small organisms. The many species all have their individual preferences for light, type of food and substratum† on which to live, so you will find different organisms in different types of aquatic habitat and so in different parts of a pond, stream or aquarium.

Collect water from a suitable source into glass or polythene jars. (If you need to transport jars containing water over more than a short distance, it is advisable to have suitable stoppers or covers for them.) With the water, take part of the substratum—mud, gravel, debris of decaying plant material and so on—and parts of living plants. If there is a green scum on the water, collect some of that. If the water is full of 'silkweed' (fine green threads), collect some of that.

### Treatment of the material at home

When you reach home, pour the samples you have collected into bowls or pie dishes,* preferably white or transparent (stand the latter on white paper). You can examine some of the water and debris at once (see later), but you will find a greater variety of organisms if you leave the containers to stand in a cool place away from strong light for at least one day.

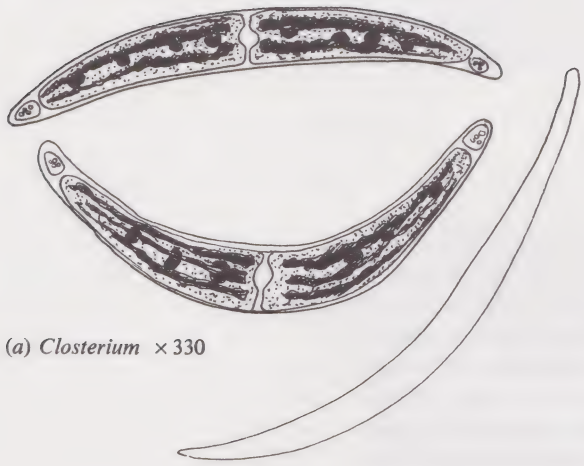
Add a small amount of dried grass or hay to some of your bowls containing water collected with mud or plant debris—this will result in some organisms, especially ciliates, becoming very numerous. You can keep a culture of dried grass in water for four or five weeks; if you examine it at intervals, you will find that different organisms become abundant in it at different times.

In your practical notebook, write down the dates on which you collect material and all details of how you treat it and what you observe in your collections whenever you examine them.

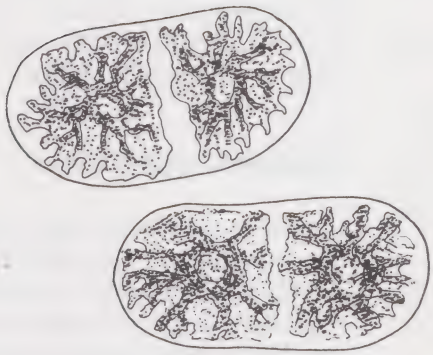
N.B. Almost certainly you will have collected some 'macroscopic' organisms such as 'worms' and 'water fleas'. You will see these moving with

* *Containers may be china, glass, polythene or enamel. Wide-mouthed jars can also be used.*

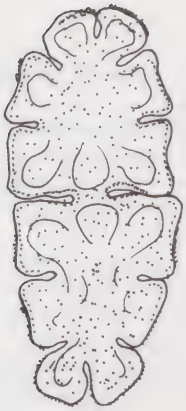
# Appendix 3



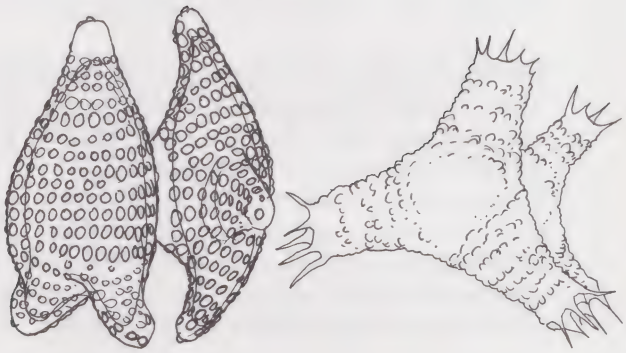
(*a*) *Closterium* ×330



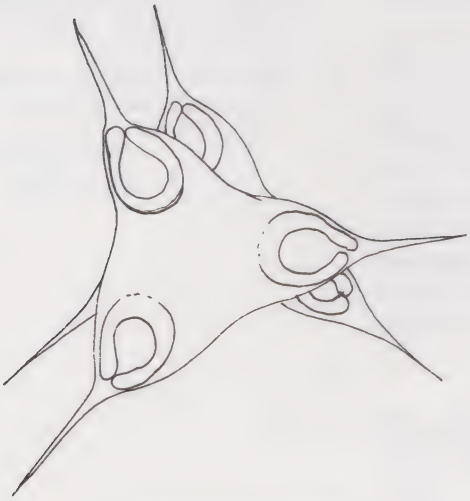
(*b*) *Cylindrocystis* ×600



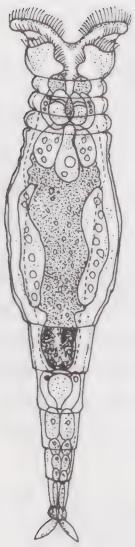
(*c*) *Euastrum* ×600



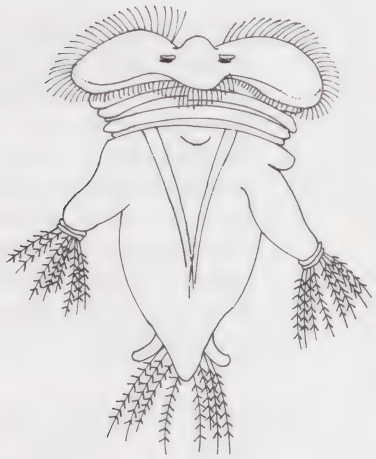
(*d*) *Staurastrum* ×600



(*e*) *Staurodesmus* ×600



(*f*) *Philodina* ×160



(*g*) *Pedalion* ×160

*Figure* 42 *Drawings of living desmids (green algae), and of rotifers as seen under the microscope.* These are green forms *except the rotifers (f) and (g).*

your 'naked' eyes, unaided by lens or microscope. They are not described in these notes and you should ignore them for the purpose of this practical work. If you wish to study them by yourself, you will probably find helpful books in your public library.

**Examination of the material**

Sample your collections by using the *dropping pipette*—essentially a glass tube tapered at one end and with a black rubber bulb over the other end. Put the open end into the water, press the bulb (bubbles then come out of the open end), then release the bulb so that water flows into the pipette. Remove the pipette from the water and release the sample on to your slide (see below) by pressing the rubber bulb again. To suck up water from a special small region of the container, you should press the bulb to push out the air bubbles with the tip of the pipette *as far away as possible* from the selected region (to avoid disturbing it), then move the pipette, pressing the bulb while you do so, to the place selected for sampling.

Use the *lying drop slide* for examining your sample under the microscope. This is a metal plate with a round hole in it. Take a clean coverslip and stick it to one side of the slide over the hole. If you turn the slide over, you now have a cavity which you can fill with water or any other fluid. To examine this under the microscope, cover the metal slide with a clean glass slide, then insert the pair of slides into your microscope (from the side) with the glass slide on top. Always examine specimens using the $\times 8$ objective first and sliding out the $\times 20$ objective when you see something of interest that needs higher magnification.

Make drawings in your notebook, like those in Figures 38 to 44, to remind you of what you have seen. Always note the magnification used beside your drawing. You will find that drawing objects forces you to examine them very carefully.

*As soon as you have sorted out your samples at home*, it is worth examining:

(a) the 'silkweed' mentioned earlier; it consists of filaments of algae, probably of green or yellow-green forms. Put a small amount of the silkweed in water in the cavity of your lying drop slide, cover with a clean glass slide and examine under the microscope. Try to identify the filaments by using the drawings in Figures 38, 39 and 40 and looking at film strip 18(a): 6, 7 and 8. Look for the following points: the shape of the cells that make up the filaments; whether the cells are all the same size; whether the filaments branch or not; the shape and number of the chloroplasts in each cell. You may find that all the filaments in your sample are the same sort or they may be a mixture of several sorts. Draw the different sorts you find.

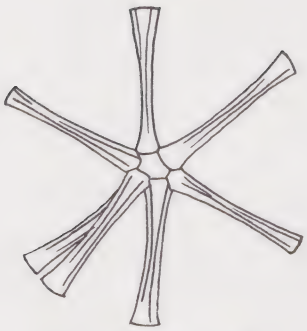
(b) the 'green scum' if any; it probably consists of blue-green algae, such as those in Figure 38, but there might be diatoms, as in Figure 43, or non-filamentous green algae, such as those in Figures 41, 42 and 44. Transfer some of the scum to your lying drop slide, cover with a plain glass slide and examine with the $\times 8$ and $\times 20$ objectives. You may find that the scum consists almost entirely of one form or of a mixture of several forms. Some of these organisms are very small and you may find it difficult to observe them clearly even with the $\times 20$ objective. Draw the organisms you can see.

Detailed instructions for preparing the lying drop slide.

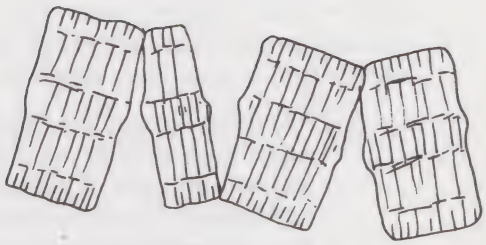
1 Melt a little candle-wax in a beaker.
2 Using a stirring-rod, put a little of the molten wax around the hole in the slide—this will harden immediately.
3 Place your gauze over one of the burners of your cooker (gas or electric) on a very low heat.
4 Place a coverslip onto the hardened wax on the metal slide, keeping the hole central under the coverslip.
5 Place the slide onto the gauze. The wax will soon melt and form a layer between the coverslip and the slide.
6 As soon as the wax has melted, remove the slide from the heat and allow to cool.
Any wax which has flowed under the coverslip can be removed with a razor blade.

ON TO THE CENTRAL AREA SHOULD BE

# Appendix 3

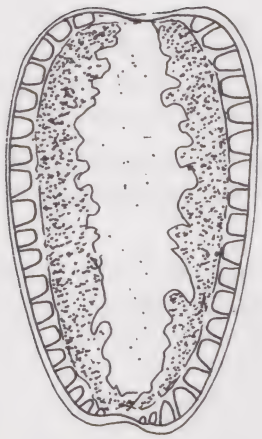


(*a*) *Asterionella* ×250

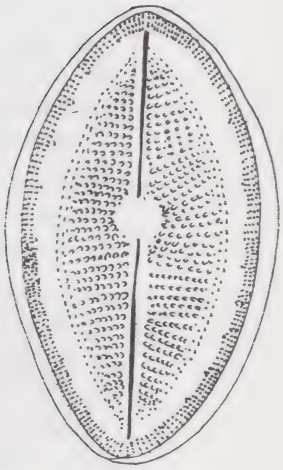


(*b*) *Tabellaria* ×250

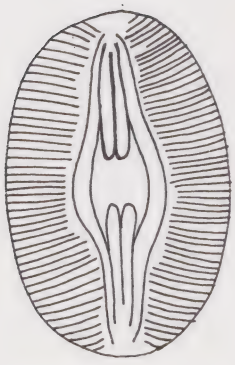
(*c*) *Navicula* ×1500



(*d*) *Sirurella* ×500



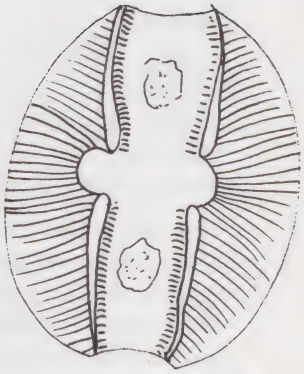
(*e*) *Cocconeis* ×1500



(*f*) *Diploneis* ×1500

(*g*) *Stauroneis* ×500

(*h*) *Cymbella* ×2000



(*j*) *Amphora* ×1000

*Figure* 43 *Drawings of living diatoms as seen under the microscope.* All these are coloured forms.

*After the water samples have stood for one or more days*, you may be able to see green water or a green film where the light is strongest and greyish films or concentrations where there is less light. Use the pipette to suck up small quantities of these green and grey films (separately) and examine each in turn in your lying drop slide under the microscope.

(a) The green water or film is likely to contain non-filamentous green algae, such as those in Figures 41, 42 and 44, or relatives of *Euglena*, shown in film strip 18(b): 9, or possibly diatoms, shown in Figure 43, or blue-green algae, shown in Figure 38. They may be very small and difficult to observe and identify.

(b) The grey films or concentrations may be protistans such as those in Figure 44 and film strip 18(b): 10 to 15. You may also have collected some multicellular organisms such as rotifers, shown in Figure 42 and film strip 18(b): 16. Ciliates appear to move fast when viewed under the microscope, so you must slow them down if you wish to observe their structure. One way of doing this is to put some cotton wool fibres in the cavity of the slide with the water. When the ciliates swim into the wool fibres, they stop and then reverse and so are more easily examined. Adding a drop of alcohol (gin or its equivalent) will also slow down ciliates.

(c) The cloudy water near the bottom of a container should also be examined and is likely to contain the same organisms as the grey films described under (b).

(d) Bits of debris should also be examined. A wide variety of organisms may be attached to the stems and leaves of dead and also of live plants; quite commonly there are diatoms or desmids, as shown in Figures 41, 42 and 43 and film strip 18(a): 3 and 3, and attached ciliates such as *Vorticella*, shown in Figure 44 and film strip 18(b): 15. *Amoeba* (film strip 18(b): 10) may be found creeping over the under-surface of leaves.

**Conclusion**

While doing this practical work, you will have exercised certain skills: collecting and sorting water samples; examining organisms selected from your samples so that you can compare and contrast those living under different conditions; using a microscope; identifying the organisms, more or less successfully, by comparison of their structure with the drawings and photographs provided in this text. All these are skills in which students reading biology at ordinary universities receive training at some stage in their careers. If you have made careful drawings of the organisms, you have practised another skill encouraged in university courses.

You can achieve even more than these practical skills if you think, as you look at these organisms, of the ways in which their structures are related to their habits of life. This interrelation between form and function is a basic theme of biology which you met when studying cells and will meet again when studying organisms in Units 19 20 and 21.

# Appendix 3

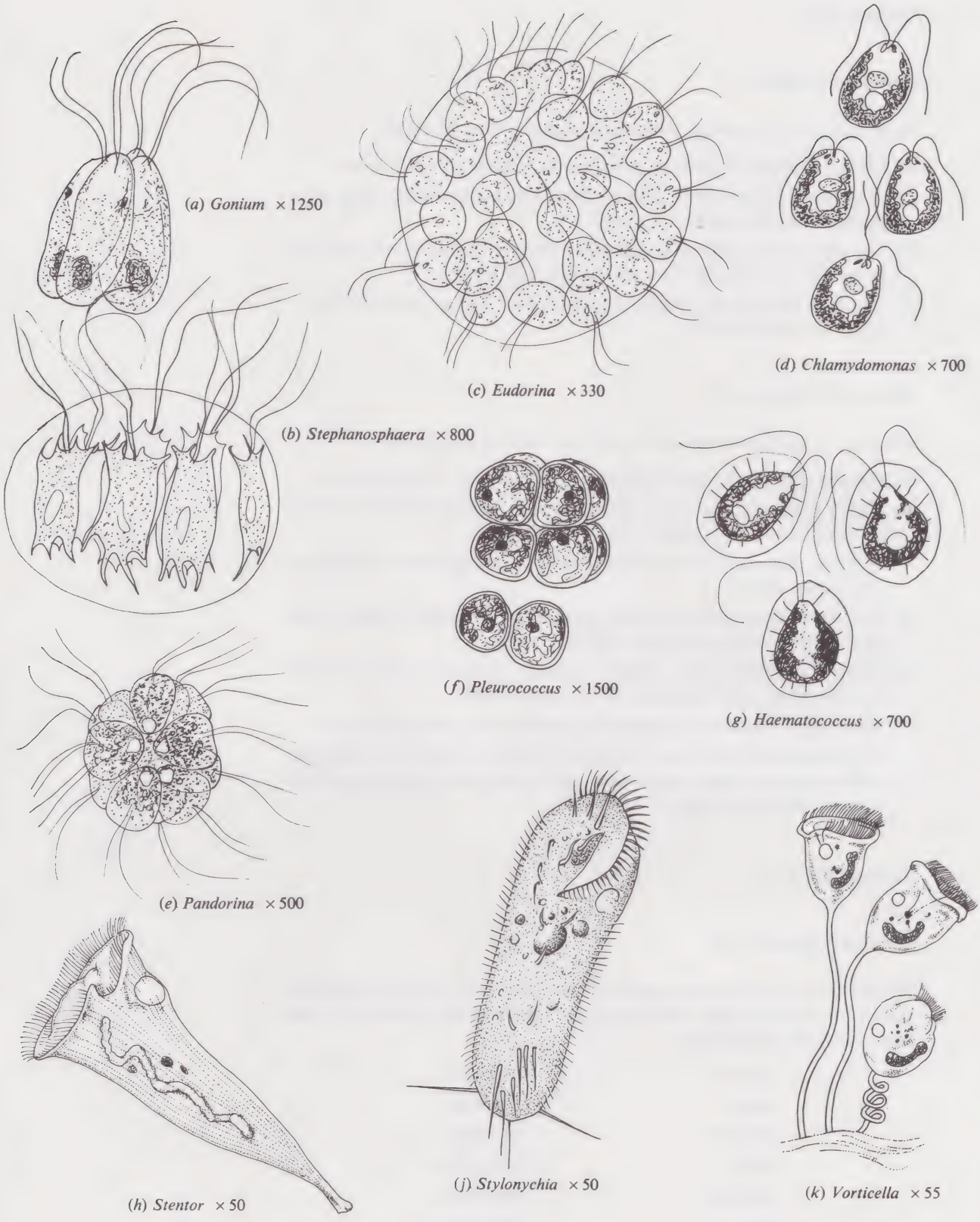



*Figure 44* ***Drawings of living protistans as seen under the microscope.*** Some of these are coloured, some are colourless.

# Self-Assessment Questions



## Section 18.1

**Question 1** (*Objective 1*)

Mark each of the following statements as either TRUE or FALSE.

(a) Some unicellular organisms can grow as large as an adult mouse.

(b) A spherical organism has a smaller surface area to volume ratio than an organism the shape of a penny.

(c) The area of cell surface is important because all substances entering or leaving the cell pass through the cell membrane.

(d) The ratio between the volume of the nucleus and the volume of cytoplasm is not important.

**Question 2** (*Objective 8*)

Imagine a hypothetical organism with the shape of a solid cube.

(a) Assume that it can absorb oxygen equally well all over its surface.

(b) That the minimum amount of oxygen that it requires for survival is proportional to its volume.

Suppose that observations on several of these organisms of different sizes have revealed:

(c) that the oxygen requirement for survival at the lowest possible level of activity is 0.01 ml/min/cm$^3$ of body volume;

(d) that the maximum rate at which oxygen can pass through the surface into the body is 0.02 ml/min/cm$^2$ of surface area.

What is the maximum possible size that this organism can attain?

If this question baffles you, work out the size of cube for which the lowest possible oxygen requirement will equal the maximum possible rate of uptake of oxygen.

## Section 18.2

**Question 3** (*Objective 1*)

Column 1 is a list of human organs and column 2 is a list of vital activities. Match the vital activities with the organs (you may use some more than once or not use them at all).

| Column 1 | Column 2 |
|---|---|
| lungs | nutrition |
| kidneys | excretion |
| brain | irritability |
| stomach | respiration |
| eye | reproduction |
| liver | growth |
| testis | movement |
| leg | |
| mouth | |

**Question 4** (*Objective 1*)

Mark each of the following statements as either TRUE or FALSE.

(a) Arteries have thick, muscular walls whereas veins have thin walls with less muscle.

(b) A portal system carries blood from one set of capillaries to another without passing through the heart on the way.

(c) Interneurons have long axons.

(d) The autonomic nervous system and brain form part of the somatic nervous system.

(e) The salivary glands are endocrine glands.

**Question 5** (*Objectives 1 and 2*)

Choose words from the list below to fill in the gaps in the two following paragraphs.

Blood from the lungs passes to the (1) side of the heart; it carries much (2) . The capacity of the blood to carry oxygen is greatly increased by the presence of the red pigment (3) in the (4) blood corpuscles. The fluid part of the blood, called (5) consists of more than 90 per cent water.

The spinal cord includes ascending (6) tracts conveying messages from the sensory nerves to the (7) . The (8) motor tracts convey messages from the brain through (9) nerves to effectors such as (10) .

red; brain; left; plasma; sensory; muscles; haemoglobin; motor; oxygen; descending.

## Section 18.3

**Question 6** (*Objective 1*)

Mark each of the following statements as either TRUE or FALSE.

(a) In each cardiac cycle, the ventricles contract before the auricles.

(b) Thyroxin affects cardiac muscle and increases the rate of heart beat.

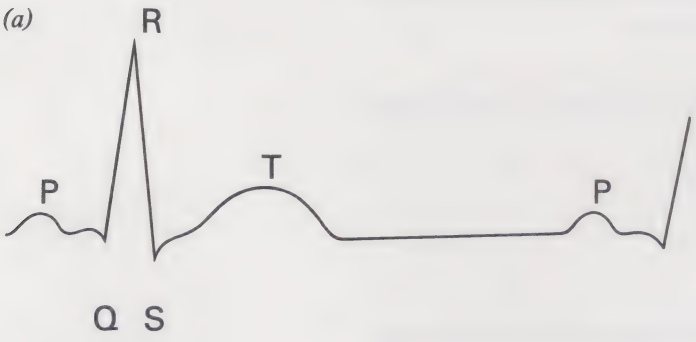
(c) The Purkinje fibres of the heart are sympathetic nerves.

(d) Parasympathetic nerves secrete adrenalin at their synapses.

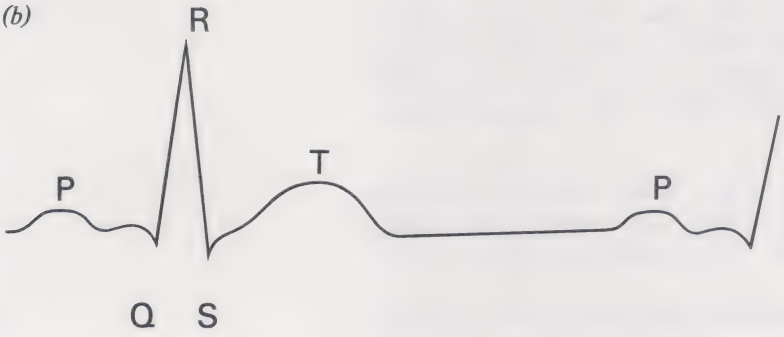
**Question 7** (*Objectives 4 and 8*)

Digitalis depresses the rate of conduction in the Purkinje fibres supplying the ventricle. Which one of the electrocardiograms below shows the effect of digitalis?

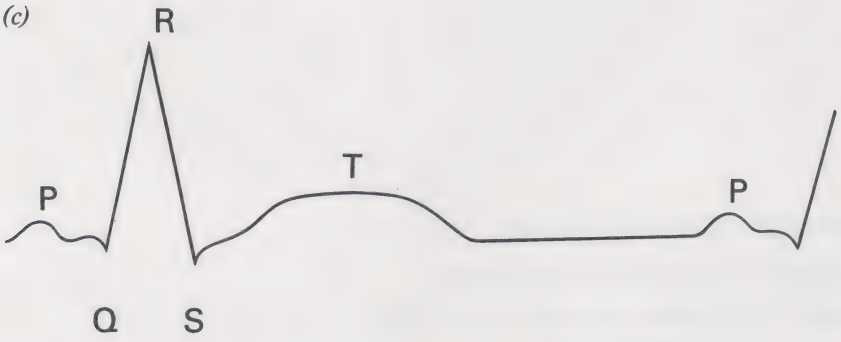
*(a)*




*(b)*



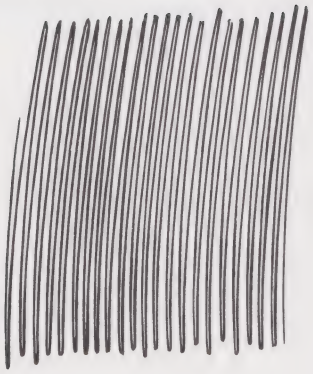

*(c)*



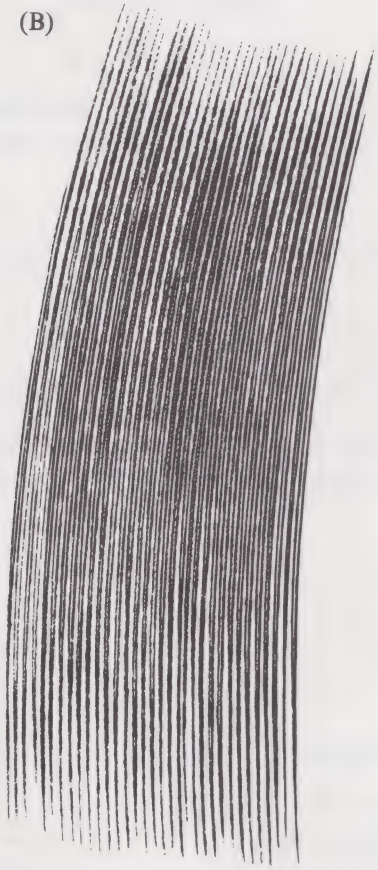
**Question 8** (*Objectives 4 and 8*)

Atropine and muscarine act antagonistically on the heart. If (B) is a kymograph record showing the effect of atropine, and one of the others is a normal heart (and all are on the same scales), which trace shows the effect of muscarine?

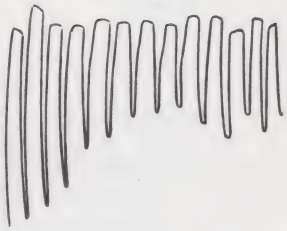
(A)



(B)



(C)



**Question 9** (*Objective 8*)

Young rats may be retarded in growth either as a result of deficiency of thyroxin or deficiency of a hormone S secreted by the pituitary gland. In a few sentences, suggest how a biologist could determine whether a group of rats showing retardation of growth were deficient in thyroxin.

**Question 10** (*Objectives 1 and 7*)

Examine the matrix.

| A | B | C |
|---|---|---|
| Nerves produce their effects quickly | Hormones have only widespread effects on the body | Hormones may affect only a few cells of the body |
| D | E | F |
| Hormones have long-lasting effects | Nerves always affect many organs at the same time | Nerves affect only a few cells at the same time |
| G | H | J |
| Hormones produce their effects slowly | Nerve stimulation acts for a short time only | Nerves transmit information by variations in frequency |

A B C D E F G H J

(a) Cross out any letters that refer to statements that are *not* true.

(b) Ring 4 letters that represent *two pairs* of statements contrasting the properties of the endocrine and nervous systems in regulation of physiological functions.

## Section 18.4

**Question 11** (*Objective 1*)

Mark each of the following statements as either TRUE or FALSE.

(a) The hypothalamus is part of the brain.

(b) Neurosecretory cells produce TRF.

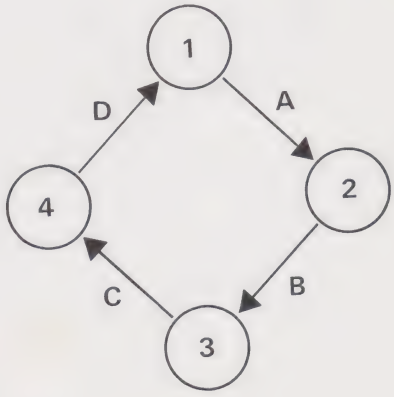
(c) The cardio-inhibitor centre in the brain controls the rate of heart beat through the sympathetic nerves.

(d) The sensors detecting cooling of the body are in the hypothalamus.

(e) Evaporation of sweat leads to cooling of the skin when small arteries are dilated.

**Question 12** (*Objective 5*)

If the adjacent diagram represents the system of control of output of thyroxin in the body, which of the following statements is the best description?




(a) If 1 is the pituitary gland, then A is TSH, 2 is the thyroid gland and D is TRF.

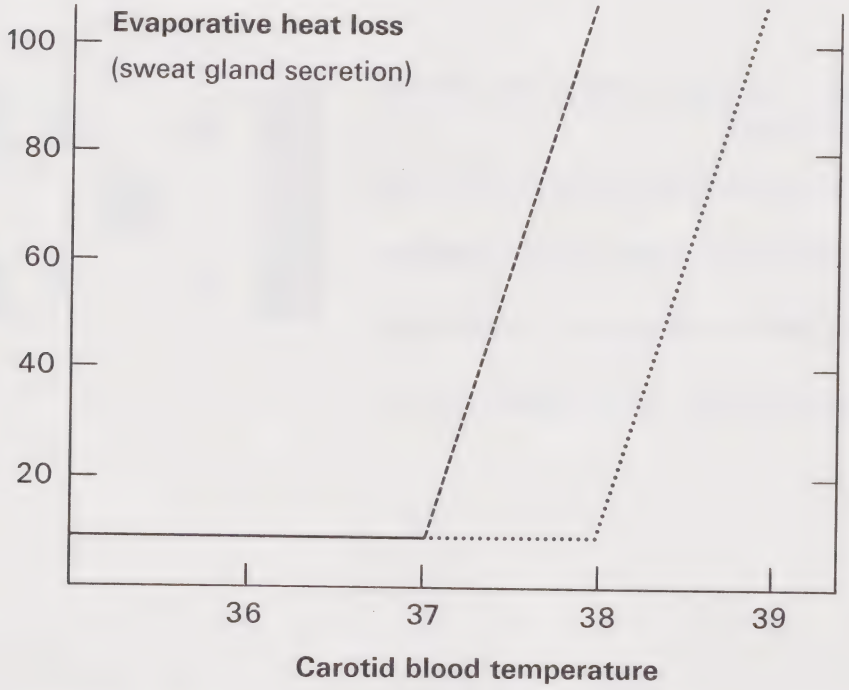
(b) If 3 is the body, then B is thyroxin, 1 is the hypothalamus and D is TRF.

(c) If 2 is the thyroid gland, then B is thyroxin, 3 is the body and D is TSH.

(d) If B is thyroxin, then 4 is the hypothalamus, D is TRF and 1 is the thyroid gland.

**Question 13** (*Objective 3*)

The graph below shows the relation between evaporative heat loss and body temperature for (1) a man with a slight fever (dotted line) and (2) a man in normal health (dashed line) under controlled conditions.




Mark the following statements as either warranted or unwarranted conclusions.

(a) The effect of fever is to constrict the small arteries of the skin.

(b) The effect of fever is to alter the activity of the sweat glands so that they secrete more sweat.

(c) The effect of fever is to raise the 'setting' of the thermostat in the hypothalamus.

(d) The effect of fever is to reduce the heart rate and so reduce the flow of blood to the skin.

## Section 18.5

**Question 14** (*Objective 1*)

Mark each of the following statements as either TRUE or FALSE.

(a) A simple reflex arc consists of a sensory neuron leading from receptor to interneuron, an interneuron and a motor neuron leading from interneuron to effector.

(b) All synapses produce acetylcholine as transmitter substance.

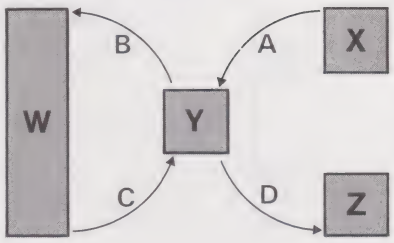
(c) The process of learning can be fully explained in terms of conditioned reflexes.

(d) An inhibitory synapse secretes a transmitter substance which modifies the post-synaptic cell membrane and makes it more difficult for the cell to fire.

(e) The hypothalamus is part of the cerebral cortex of the brain.

**Question 15** (*Objective 5*)

If the diagram below represents a reflex arc, which of the following statements represents the best description?




(a) If Y is the interneuron, then X is the brain, D is the motor neuron and W is the receptor.

(b) If W is the brain, then A is the sensory neuron, B is the ascending neuron and Z is the effector.

(c) If C is the descending neuron, then X is the receptor, B is the motor neuron and Z is the brain.

(d) If W is the brain, then Y is the interneuron, X is the receptor and Z is the effector.

## All Sections

**Question 16** (*Objective 6*)

Mark the following statements as either TELEOLOGICAL or NOT TELEOLOGICAL. Turn those which you consider to be teleological into a non-teleological form:

(a) During exercise, the sweat glands secrete to cool the body.

(b) Increased venous pressure affects the cardio-accelerator centre and the heart rate is increased.

(c) Sudden fright leads to the secretion of adrenalin which causes increase in the rate of heart beat.

(d) A frightened man secretes adrenalin in order to dilate the arteries supplying the heart and brain.

(e) The hypothalamus secretes TRF to stimulate the pituitary to secrete TSH to stimulate the thyroid gland to secrete thyroxin.

(f) Increase in the level of thyroxin circulating in the blood inhibits the pituitary from secreting TSH.

(g) When I feel cold, I jump up and down to warm myself.

# Self-Assessment Questions

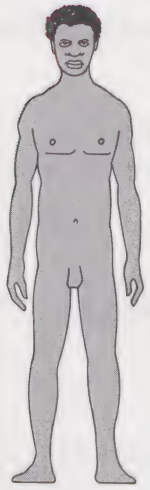
**Question 17** (*Objective 8*)

In the human body, heat is produced inside the body and heat loss occurs through the surface of the body. Show how these two facts can be used to explain the following observations:

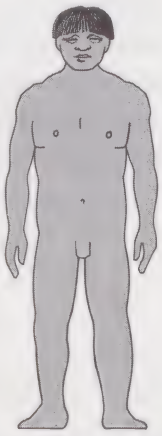
(a) In icy water, short, fat men survive longer than tall, thin men.

(b) When people who are asleep are cold, they move their knees up towards their stomachs and clasp their arms round their bodies. If the same people are hot while they are asleep, they roll over on to their backs with their knees apart and arms and legs stretched out away from the body.

(c) The bodily proportions of native peoples from the tropical Sudan and the Canadian Arctic are very different as you can see by comparing the drawings alongside.



Dinka from
tropical Sudan
Height: 1·88 metres



Eskimo from
Canadian Arctic
Height: 1.65 metres

**Question 18** (*Objective 8*)

A biologist suspects that an organ N secretes a hormone that causes an effect F in a given species of animal. Suggest at least two experiments that he could try to test whether his hypothesis is true.

**Question 19** (*Objective 3*)

Consider each of the pairs below:

if an increase in the first causes an increase in the second—write A

if an increase in the second causes an increase in the first—write B

if an increase in the first causes a decrease in the second—write C

if an increase in the second causes a decrease in the first—write D

if an increase in either has no effect on the other—write E

(a) thyroxin in the blood / adrenalin in the blood

(b) impulses in the vagus nerve / rate of heart beat

(c) pressure on skin receptors / impulses in the sensory nerve

(d) temperature of the blood / shivering of body muscles

(e) rate of heart beat / acetylcholine in the blood

(f) temperature of the skin / dilation of skin capillaries

(g) temperature of the air / secretion of sweat glands

(h) thyroxin in the blood / TSH in the blood

**Question 20** (*Objectives 1 and 5*)

Examine the following matrix.

| A | B | G | H |
|---|---|---|---|
| Receptor for normal stimulus | Descending neuron | Somatic sensory nerve | Hormone |
| **C** | **D** | **J** | **K** |
| Neurons of cerebral cortex | Parasympathetic nerves | Sympathetic nerves | Receptor for second stimulus |
| **E** | **F** | **L** | **M** |
| Interneurons | Effector | Ascending neuron | Somatic motor nerve |

Using the appropriate letter for each component, list the essential components of the following:

(a) spinal reflex arc
(b) conditioned reflex
(c) learning process
(d) alarm reaction
(e) supression of reflex
(f) writing this answer.

## Attempt after this Unit's TV Programme and Reading the Broadcast Notes

**Question 21** (*Objective 8*)

Look at the two kymograph records shown in the broadcast notes. Each record reads from left to right and starts with a normal heart beating. The drugs were added at the times indicated by the arrows. The time marker was set at the same speed for both records, but the vertical movement of the lever was set differently; this explains why the normal heart beats at the beginning of the two records differ in height and shape.

The effects of adding adrenalin and acetylcholine to the perfusion fluid are clearly different even to casual inspection. Scientific observations should be expressed in exact terms—which means quantitatively, if possible. Now examine the two records carefully and assess in quantitative terms how the beat of the rabbit's heart is affected by the addition of adrenalin and by the addition of acetylcholine—write a paragraph about the effects of each drug. When you have done this, make a list of the differences between the effects of the two drugs.

# Self-Assessment Answers and Comments

## Question 1

These are either true or not.

(a) False—(18.1.0).

(b) True—remember your observations on the easily deformable solid—(18.1.1).

(c) True—(18.1.1).

(d) False—(18.1.2).

## Question 2

The maximum possible size for this hypothetical organism is a cube with sides of 12 cm. The principle involved in this calculation is that the surface area to volume ratio falls as the linear dimensions increase, given that the shape remains the same, (18.1.1).

There are several possible ways of working out the value—here is one way.

The minimum oxygen requirement is proportional to the volume of the organism and is 0.01 ml/min/cm$^3$ (from statements b and c) so for a cube with sides of length $p$, the minimum oxygen requirements will be $0.01 \times p^3$ ml/min—since the volume of a cube with sides of length $p$ is $p^3$ (18.1.1).

The maximum rate at which oxygen can pass into the body is proportional to the surface area of the organism and is 0.02 ml/min/cm$^2$ (from statements a and d), so, for a cube of sides of length $p$, the maximum rate of oxygen uptake will be $0.02 \times 6p^2$ ml/min—since the total area of a cube with sides of length $p$ is $6p^2$ (18.1.1).

The maximum possible size for this hypothetical organism is that at which the maximum possible uptake of oxygen just balances the minimum oxygen requirement; the organism can grow no bigger than this because it cannot take up enough oxygen.

So $p$ (the length of sides of the cube) is at its greatest value when:

$$0.01 \times p^3 = 0.02 \times 6p^2 \text{ ml/min.}$$

Dividing each side by $p^2$, gives:

$$0.01 \times p = 0.12$$

Therefore $p = 12$ cm.

**Question 3**

Read section 18.2.2 if you have made any mistakes in the following:

| *organ* | *vital activity* |
|---|---|
| lungs | respiration |
| kidneys | excretion |
| brain | irritability (and co-ordinates movement) |
| stomach | nutrition |
| eye | irritability |
| liver | nutrition and growth |
| testis | reproduction |
| leg | movement |
| mouth | nutrition, respiration, excretion (of carbon dioxide) irritability, (through taste buds) |

**Question 4**

These are either true statements of fact or not.

(a) True—(18.2.3)
(b) True—(18.2.3)
(c) False—(18.2.4)
(d) False—(18.2.4)
(e) False—(18.2.5)

**Question 5**

The paragraph should read as follows.

Blood from the lungs passes to the left side of the heart; it carries much oxygen. The capacity of the blood to carry oxygen is greatly increased by the presence of the red pigment haemoglobin in the red blood corpuscles. The fluid part of the blood, called plasma, consists of more than 90 per cent water (18.2.3).

The spinal cord includes ascending sensory tracts conveying messages from the sensory nerves to the brain. The descending motor tracts convey messages from the brain through motor nerves to effectors such as muscles (18.2.4 and Fig. 11, p. 25).

**Question 6**

These are either true statements of fact or not.

(a) False—(18.3.2)
(b) False—(18.3.4). If you said 'true', you may be confusing thyroxin with adrenalin (which does affect cardiac muscles in this way).
(c) False—they are modified cardiac muscle cells (18.3.2).
(d) False—parasympathetic nerves, such as the vagus, secrete acetylcholine; it is the sympathetic nerves which secrete a substance closely related to adrenalin (18.3.4).

**Question 7**

B—(18.3.4).

A is a normal electrocardiogram.

B shows a longer interval between P (when the auricle contracts) and Q as the ventricle begins to contract—this is the effect of digitalis.

C shows no change in PQ, but the QRST intervals are all increased; digitalis must lengthen the PQ interval so this cannot be the correct trace.

**Question 8**

C—(18.3.2)

B shows the effect of atropine—this record shows the contractions as faster and of greater strength than either A or C. If muscarine acts antagonistically, it should produce the opposite effect on the heart rate, i.e. the record should show contractions which are slower and less strong than normal. Hence C shows the effect of muscarine, and A is the normal heart, showing both rate and strength of contractions as intermediate between B and C.

**Question 9**

There are two approaches (18.3.4).

First, to produce normal growth in the group of deficient rats by making good the deficiency:

> if giving them thyroxin leads to normal growth, then they were probably deficient in thyroxin;
>
> if giving them hormone S leads to normal growth, they were probably deficient in hormone S.

The second approach is to operate on normal rats in such a way as to produce the same pattern of retarded growth:

> if removing the thyroid glands leads to this type of retarded growth, the group of retarded rats were probably suffering from deficiency of thyroxin;
>
> if removing the pituitary leads to retarded growth, then the original rats were probably suffering from deficiency of hormone S.

However, there may be other side effects of these operations, especially of removal of the pituitary, and these might invalidate the whole of this procedure.

If the operations were possible and successful, then a final experiment giving the operated rats either thyroxin or hormone S (as appropriate) and so restoring their growth to normal would give strong confirmation that the conclusions from the results of the operations were correct.

In both sets of experiments, there should be adequate 'controls':

> retarded rats given 'neutral' substances instead of thyroxin or hormone S; normal rats subjected to dummy operations simulating removal of the thyroid or pituitary glands.

**Question 10**

(a) Cross out:

B (some hormones, such as TSH affect only a few cells—as stated by C).

E (many nerves supply only a few cells—as stated in F).

The other statements are all true.

(b) Possible pairs are:

A and G; D and H.

The other true statements do not form pairs.

**Question 11**

These are either true statements of fact or not.

(a) True—(18.4.1).

(b) True—(18.4.1).

(c) False—the cardio-inhibitor centre acts through the parasympathetic system, i.e. the vagus nerve—(18.4.2).

(d) False—sensors in the hypothalamus detect increase (not decrease) in blood temperature; the sensors detecting cooling are in the skin—(18.4.3).

(e) True—(18.4.3).

**Question 12**

(a) is the best answer—it is the only answer in which the statements are all consistent with each other (Fig. 26, p. 41, and 18.4.1).

(a) is a correct statement—4 would be the hypothalamus, releasing TRF.

(b) is not correct—1 cannot be the hypothalamus, if the other statements are true 4 must be the hypothalamus.

(c) is not correct—D must be TRF, 1 must be the pituitary and A must be TSH, if the first three statements in (c) are true.

(d) is not correct—1 must be the pituitary gland and 2 the thyroid gland, if the first three statements in (d) are true.

**Question 13**

(c) is a warranted conclusion; (a), (b) and (d) are unwarranted.

The difference between the normal man and the man with slight fever is that the graph for the latter is displaced to the right of that for the former; the two are identical in shape, but the slope changes at 37° C for the normal man and 38° C for the feverish man. This means that the body temperature rises an extra 1° C before the man with the fever starts to lose heat, compared with the normal man; but the feverish man loses heat in exactly the same way as the normal man once he has started to do so. Statement (c) is the only one that is consistent with the above interpretation of the graphs. If the setting of the thermostat in the hypothalamus were raised by 1° C, but no other adjustment made, then this would explain the difference between the two graphs.

(Read section 18.4.3 to revise what happens in the normal man.)

**Question 14**

These are either true statements of fact or not.

(a) True—(18.5.1 and Fig. 33, p. 50).

(b) False—synapses between motor nerves and skeletal muscle uses acetylcholine as transmitter and so do some others but a substance like adrenalin is the transmitter at the end of sympathetic nerves (18.4.3). While synapses in the brain and between descending neurons of the spinal cord and interneurons may use yet other transmitter substances (18.5.2 and 18.5.3).

(c) False—(18.5.2). It is doubtful whether this statement will ever be true.

(d) True—(18.5.1).

(e) False—hypothalamus and cerebral cortex are both parts of the brain—Fig. 23, p. 39).

**Question 15**

(d), with (b) as the next best answer.

(a) This statement does not explain why arrow B exists—what connection apart from C (sensory neuron) could there be between interneuron (Y) and receptor (W)?

(b) This could be true, all the included statements are consistent.

(c) If C is the descending neuron, then W must be the brain not Z, and B should be the ascending neuron, D the motor neuron and Z the effector.

(d) This could be true, all the included statements are consistent
You were asked to choose the 'best' description, so you must exercise your judgement as to which of the two consistent statements (b) and (d) is the better one.

(b) is rather difficult to follow since it includes both boxes (W and Z) and arrows (A and B) in an order which is not logical.

(d) identifies only the boxes, but deals with them in a logical sequence; given that the boxes are properly identified, anyone with the appropriate knowledge can identify the arrows.

So (d) is the clearer statement and therefore a better answer than (b). (Look at Fig. 34 (p. 52) for another diagram of this type of reflex arc.)

**Question 16**

(Read section 18.3.1 for a discussion of teleology.)

(a) Teleological—the statement implies that the sweat glands secrete with the purpose of cooling the body. 'During exercise, the sweat glands secrete and the body is cooled' is a statement of fact and therefore not teleological.

(b) This sentence is a statement of fact and therefore not teleological.

(c) This sentence also is not teleological—the secretion of adrenalin does cause increase in the rate of heart beat, as we can show by experiment.

(d) Teleological—the frightened man has no conscious control over the secretion of adrenalin, even if he had the conscious intention of dilating the arteries supplying the brain. 'A frightened man secretes adrenalin and this has the effect of dilating the arteries supplying the heart and brain' is acceptable as a non-teleological statement.

(e) Teleological—it is rather easy to write carelessly in this way and to imply a chain of purposive events. 'The hypothalamus secretes TRF which stimulates the pituitary to secrete TSH and this stimulates the thyroid gland to secrete thyroxin' is a series of statements of the results of experimental observations.

(f) This sentence is not teleological—it describes experimental observations.

(g) This statement is acceptable because I am responsible for such actions and I have a conscious purpose, that of warming myself, when I jump up and down. The statement would not be acceptable if made about a child who was not old enough to have made a mental correlation between jumping up and down and feeling warmer. In this case; 'When children are cold and jump up and down, they warm up' would be a better statement.

**Question 17**

(This is based on section 18.1.1. *SAQ* 2 is also relevant.)

(a) Short, fat men are closer to a sphere in shape, and tall, thin men to a long sausage—so the former have a lower surface area to volume ratio than the former. The amount of heat produced inside the body might be exactly the same in the two types of men, but the rate of heat loss, being proportional to surface area would be higher in the tall, thin men. Their body temperatures will thus fall more rapidly so they will die sooner from cold than will the others. Of course, the short, fat men may also benefit from having a thicker layer of insulation under the skin.

(b) The hunched-up position with arms clasped round the body, exposes less surface area through which heat can be lost than does the stretched out position. The sleepers' unconscious movements result in reduction of heat loss when the body is cold and increased heat loss when the body is warm.

(c) The Dinka is tall and thin with relatively very long legs; the Eskimo is short and fat, with relatively short legs—thus the former has a greater surface area to volume ratio than the latter. It is possible that the two are equally efficient at producing heat within the body, but the Dinka is likely to lose heat far more rapidly than the Eskimo. Each is very well adapted to the climatic conditions of his native land—in the cold Arctic, conservation of heat is a major problem and those that conserve heat most efficiently are most likely to survive. In the tropical heat of the southern Sudan, there is some danger of overheating, so people with a high capacity to lose heat may survive when others die. When you have read Unit 19 you will realize that the distinctive characteristics of these two races of men can be interpreted as the results of natural selection acting for many generations—Eskimos are now well adapted for life in the cold Arctic, and Dinkas for life in the hot Tropics.

**Question 18**

(This is based on 18.3.4.2 and *SAQ* 9 is also relevant.)

First, the biologist could remove the organ N from a number of animals and observe whether or not the effect F occurred. There should be 'control' animals subjected to dummy operations. If the effect did not occur in the absence of organ N, he could argue that the organ was necessary in some way. Secondly, the biologist could treat animals from which he had removed the organ N with extracts made from this organ. If the effect F then occurred, he could argue that the extract from N had promoted the effect F which had not occurred in the absence of the organ N. He could proceed to make and purify an extract from organ N and so identify the hormone.

Thirdly, the biologist could treat animals from which he had removed the organ N with blood or some other tissue fluid from normal animals. If the effect F occurred, he could argue that the blood of normal animals contained some substance which promoted the effect F and which was not present in the blood of animals which lacked the organ N. He could then extract and purify the blood or fluid until he had isolated the chemical substance (the hormone). He could then make extracts from the organ N and investigate whether they contained the same substance. He should also show that no other organ contained this substance (except in so far as it would be present in the blood supply to that organ).

The biologist should have suitable 'controls' for all his experiments—animals given extracts of organs other than N, and so on.

**Question 19**

(a) E—the two have no effect on each other.

(b) C—stimulation of the vagus nerve leads to decrease in rate of heart beat (18.3.3).

(c) A—pressure on skin receptors is translated into impulses in the sensory nerve (18.5.1).

(d) B—shivering of body muscles leads to increased temperature of blood as a result of the exothermic reactions occurring in the active muscles (18.4.3).

(e) D—perfusion of the heart with acetylcholine leads to slowing of the beat (TV programme).

(f) B—dilated skin capillaries go with warm, pink skin whereas constricted capillaries are associated with blue or white cold skin (18.4.3).

(g) A—when the air temperature rises sufficiently for the blood to become warmer than 37° C, then the hypothalamic centre becomes active and the sweat glands secrete (18.4.3).

(h) C and B—the homeostatic mechanism controlling the level of thyroxin in the blood depends on negative feedback between the level of thyroxin and TSH (as indicated by C); but there is positive response of the thyroid gland to increase in the level of TSH (as indicated by B), so the levels of the two hormones fluctuate about a controlled level (18.4.1).

**Question 20**

(18.5.1, 18.5.2, 18.5.3, and 18.4.2)

(a) A–G–E–M–F

(b) First A–G–E–M–F, then A and K–G–E–M–F, then K–G–E–M–F.

(c) C is essential. A–G–E–L–C–B–E–M–F is possible for a learned action.

(d) A–G–E–L–E–J–H expresses the secretion of adrenalin (the second E is in the brain).

(e) A–G–E–L–C–B–E accompanied by K–G–C.

(f) A–G–C–B–E–M–F assuming you are reading and then writing after thought.

**Question 21**

You can measure two characteristics of the records:

1 the rate of contraction of the heart and

2 the extent of the contractions.

The rate of contraction (1) is derived by counting the number of contractions 'per unit time'. An easy way to do this is to measure with a ruler the length of time marker trace for 10 marks; then move the ruler up and count the number of contractions that occurred along this length of heart beat trace. The number is most easily counted by looking either at the top or bottom edge of the trace. You will then have the *number of contractions per ten time marks*.

The extent of the contractions (2) is derived by measuring the vertical distance between the upper and lower ends of the trace for any one or more contractions.

Here is an example of the observations which you may have written in your notebook:

| *Adrenalin record* | *Number of contractions per ten time marks* | *Height of typical contractions* |
|---|---|---|
| Normal heart (at beginning of trace | 18 | 1.3 cm |
| Where height of contractions is greatest | 37 | 2.7 cm |
| At right-hand side of record | 35 | 1.7 cm |

The height of contractions was greatest about 24 time marks after the adrenalin was added (the point of the arrow). The shape of the record changes about 12 time marks (or 22 contractions) after the adrenalin was added. The right-hand end of the record is about 50 time marks after the adrenalin was added.

| *Acetylcholine record* | *Number of contractions per ten time marks* | *Height of typical contractions* |
|---|---|---|
| Normal heart (at beginning of trace) | 15 | 0.7 cm |
| At right-hand side of record | 2.5 | 0.4 cm |

The shape of the record changes about 22 time marks (or 32 contractions) after the acetylcholine was added. The record is then rather irregular.

After writing down these figures, you should have written two paragraphs similar to the following.

*After adrenalin was added to the perfusion fluid*, there was an interval of approximately 12 time marks (or 22 heart beats) when the beat continued to be normal, with a rate of about 1.8 contractions per time mark and a height of approximately 1.3 cm. After this interval, the rate of beat rapidly increased to approximately twice the normal rate (about 3.7 beats per time mark); it had slowed down slightly (to about 3.5 beats per time mark) by the end of the record. The maximum height of the contraction was about double that of the normal heart (2.7 cm); these strong contractions occurred approximately 24 time marks after the addition of adrenalin (or about 12 time marks after the beat began to change shape and rate). The height of the contraction had returned towards the normal level by the end of the record but was still greater than normal (1.7 cm compared with 1.3 cm).

*After acetylcholine was added to the perfusion fluid*, there was an interval of approximately 22 time marks (or 32 heart beats) when the beat continued to be normal, with a rate of about 1.5 contractions per time mark and a height of approximately 0.7 cm. The rate of heart beat then slowed down and became irregular. At the end of the record, the rate of beat was approximately 0.16 the normal rate (or 1/6 the normal rate—0.25 beats per time mark). The height of the contractions was reduced and was about 0.6 the normal height (0.4 cm compared with 0.7 cm) at that time.

Comparing these two paragraphs, you might have listed the following differences between the effects of the two drugs on the rabbit's heart beat:

1 Adrenalin increased the rate of heart beat to about 2 × normal whereas acetylcholine decreased the rate of heart beat to about 0.16 × normal rate.

2 Adrenalin increased the strength (or height) of the contraction to a maximum of about 2 × normal, whereas acetylcholine decreased the strength of contraction to about 0.6 × normal.

3 Within the time recorded on the traces, the effect of the adrenalin appeared to be wearing off (the heart beat had returned towards normal to a small extent in rate, but more markedly in strength), whereas there was no indication that the effect of acetylcholine was wearing off.

4 The time interval between the addition of drug to the perfusion fluid and the change in pattern of the heart beat was nearly twice as long for acetylcholine as it was for adrenalin (22 compared with 12 time marks).

**Further question**

Do you consider this difference in time interval (difference (4) above) to be a real difference between the effects of the two drugs on the heart? Or could the difference in time interval be explained in some other way? If you think it could, suggest an explanation.

**Answer to the further question**

Dr. Holmes explained during the Unit's TV demonstration that the time interval is partly the result of the drug being injected into the perfusion fluid before the fluid enters the heart. The rate at which the perfusion fluid is flowing down the tube to the heart will affect the time interval between adding the drug and observing a change in the heart beat. Thus, without information about the rate of flow of the perfusion fluid, it is not possible to assess whether the observed difference between the two records is a real difference between the effects of the two drugs.

## Captions for Film Strips

### 18(a) Photographs of freshwater Algae (including green Protistans)

1 *Chlamydomonas* (400×), a green alga. Note the pair of cilia of equal length and the single chloroplast.

2 *Volvox* (40×), a colonial green alga. Each individual in each colony resembles an individual *Chlamydomonas*. Note the small daughter colonies inside the large colony.

3 *Navicula* (400×), a diatom. The individuals look different because they are viewed from different angles. Markings on the siliceous cell wall can be seen faintly on the diatom just above the number.

4 *Micrasterias* (125×), a desmid. Note the division into two 'semi-cells', each with a complicated outline and the mirror image of the other. The edge of another individual can be seen in the lower left-hand corner, attached to the desmid filling the centre of the picture.

5 *Ceratium* (125×), a dinoflagellate. The firm outline is made possible by plates of cellulose, forming, in this organism, three spines. The groove round the middle is a characteristic feature of dinoflagellates.

6 *Anabaena* (125×), a blue-green filamentous alga. The individual cells look like beads in a necklace.

7 A solitary blue-green alga (160×) and *Zygnema* (160×), a filamentous green alga. You can see two cells of the filament—note the characteristic chloroplast, like a double star, in each cell.

8 *Spirogyra* (160×), a filamentous green alga. Parts of two filaments are shown, of different species. Note the very characteristic spirally arranged chloroplasts. The upper filament shows a wall between two cells of the filament.

### 18(b) Photographs of freshwater Protistans

9 *Euglena* (160×). Note the green chloroplasts. Each organism has a single long cilium. Compare these photographs with the model shown in the broadcast notes.

10 *Amoeba* (80×). Note the spherical contractile vacuole near the upper end and the short pseudopodia. Compare this photograph with the model shown in the broadcast notes.

11 *Arcella* (200×). Like *Amoeba*, this organism moves by means of pseudopodia, but the body is largely enclosed in a shell whose texture can be seen as a reddish ring.

12 *Paramoecium* (125×), a ciliate. One spherical contractile vacuole is visible; the gullet can be seen as a groove near the other side of the body. Note the cilia, clearly visible round the outside, and the food vacuoles inside the body. Compare this photograph with the model shown in the broadcast notes.

13 *Didinium* (on the left) and *Paramoecium* (100×), both ciliates. *Didinium* is a predatory ciliate, about to attack the *Paramoecium* and swallow it through the 'mouth' which projects and touches the *Paramoecium*. *Didinium* has two girdles of cilia seen as projections in the photograph.

14 *Vorticella* (25×), a stalked ciliate. These individuals are attached to a strand of *Anabaena* (see film strip 18(a): 6). The large cilia at the free end create water currents which bring food to the organism.

15 A culture of mixed ciliates (50×). Many are clustered round a strand of *Spirogyra*, others are swimming freely.

16 A Rotifer (80×). This is not a Protistan but a multicellular organism. It has many cilia at the front end and swims by means of ciliary activity. The organs inside the transparent body include a stomach and jaws. The body ends in a short, forked tail (not shown) by which the animal can attach itself. There are many other species of rotifers. They can easily be mistaken for ciliates but you should be able to see the internal organs and so distinguish them.

## 18(c) Photographs of microscopic preparations illustrating the blood vascular system

1 Human blood—a stained smear of blood, magnified $\times 900$. Note: many red blood corpuscles (two are labelled E) without nuclei; a few white blood corpuscles (two are labelled L) with darkly stained nuclei; a few platelets (labelled T)—these are small structures concerned with clotting.

2 Electron micrograph of a white blood corpuscle that has engulfed some bacteria (labelled B). The line labelled 1 $\mu$ represents a length of $1 \times 10^{-6}$ m (magnification $\times 25\,000$).

3 A stained section through mammal tissue, showing an artery (labelled A) and a vein (labelled V) cut across, magnified $\times 35$. The three layers that comprise the wall of the artery are numbered: 1 is a thin layer of lining cells; 2 is a thick layer of muscle cells (stained red) and elastic fibres (stained purple); 3 is a layer of connective tissue (stained blue). Compare this artery wall with the wall of the vein. Inside both vessels is blood (stained red)—compare this with the smear (no. 1).

4 A stained section through a mammal lung with the blood vessels injected with red pigment, magnified $\times 360$. Note the small artery (labelled A) with a smaller arteriole cut lengthways branching from it. Capillaries are labelled at C—compare these with the artery and arteriole. The unstained spaces are filled with air during life. Note the narrow tissue barrier separating the air spaces from the blood in the capillaries.

5 A stained lymph vessel, magnified $\times 60$. Valves (labelled V) are present similar to those in veins. The direction of flow is shown by the arrow. When the lymph is flowing, the valves are pressed flat against the walls of the vessel; by filling up and bulging to block the vessel, the valves prevent back-flow of fluid.

6 A stained section through a rat's heart, magnified $\times 4$. Note the four chambers of the heart:

RA = right auricle; LA = left auricle;
RV = right ventricle; LV = left ventricle.

Note also the mass of cardiac muscle (labelled C). The arrow points to one of the valves between the right auricle and right ventricle: it is in the open position, allowing blood to flow from the auricle to the ventricle. Part of a second valve is also visible—there are three on the right side and two on the left side of the heart.

7 A stained section through a rat's heart, cut at right angles to that shown in 6 and passing through the two ventricles (labelled LV and RV), magnified $\times 6$. Note the difference in thickness between the walls of the two ventricles.

**Suggest an explanation for this.**

The arrow points to a small branch of the coronary artery; this supplies blood to the cardiac muscles, taking it from the artery supplying the body soon after it leaves the left ventricle.

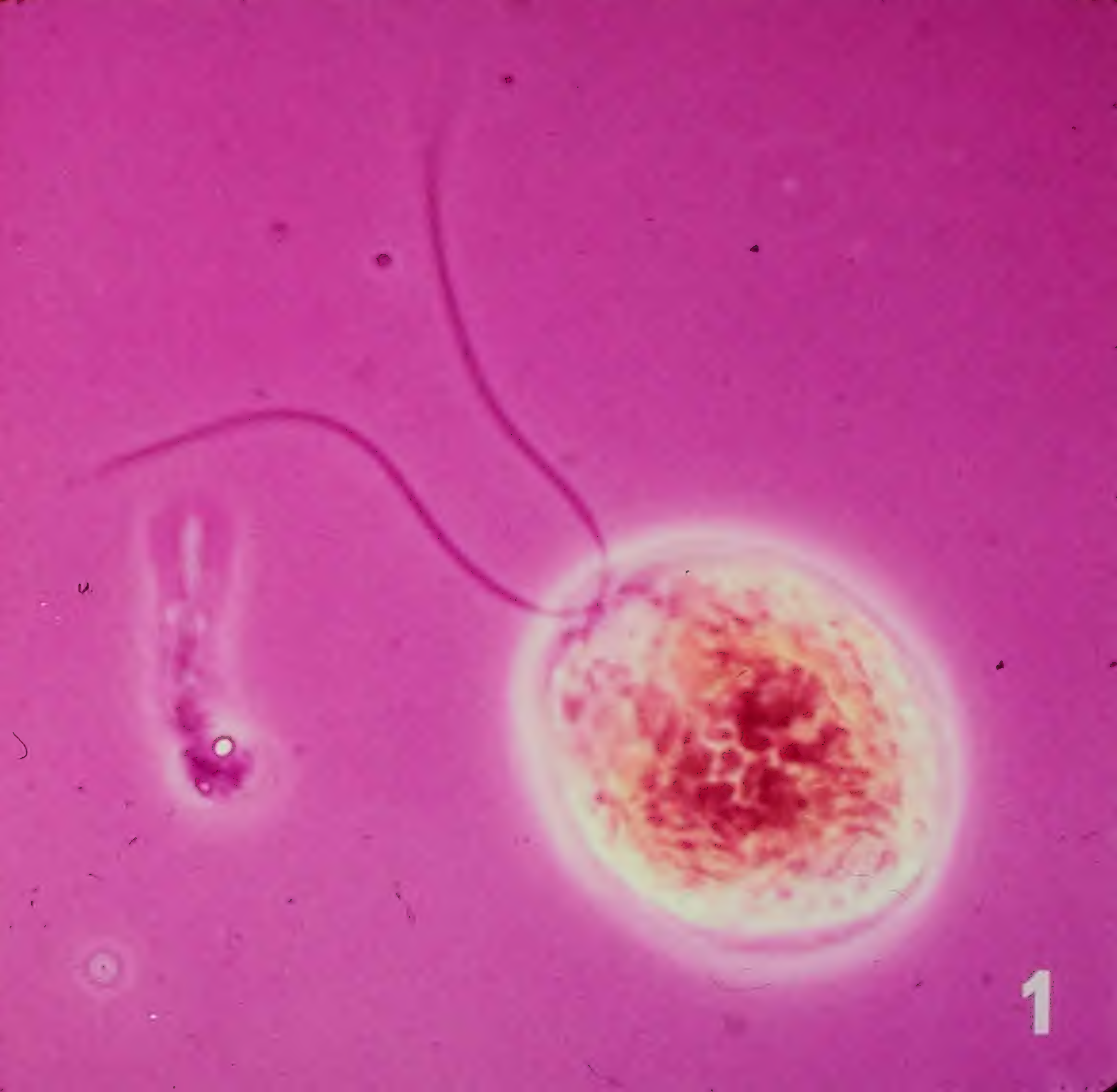
Blood from the left ventricle is circulated all round the body whereas that from the right ventricle goes only to the lungs. The differences in amount of muscular tissue in the two ventricles reflect the differences in the extent of the two circulations.

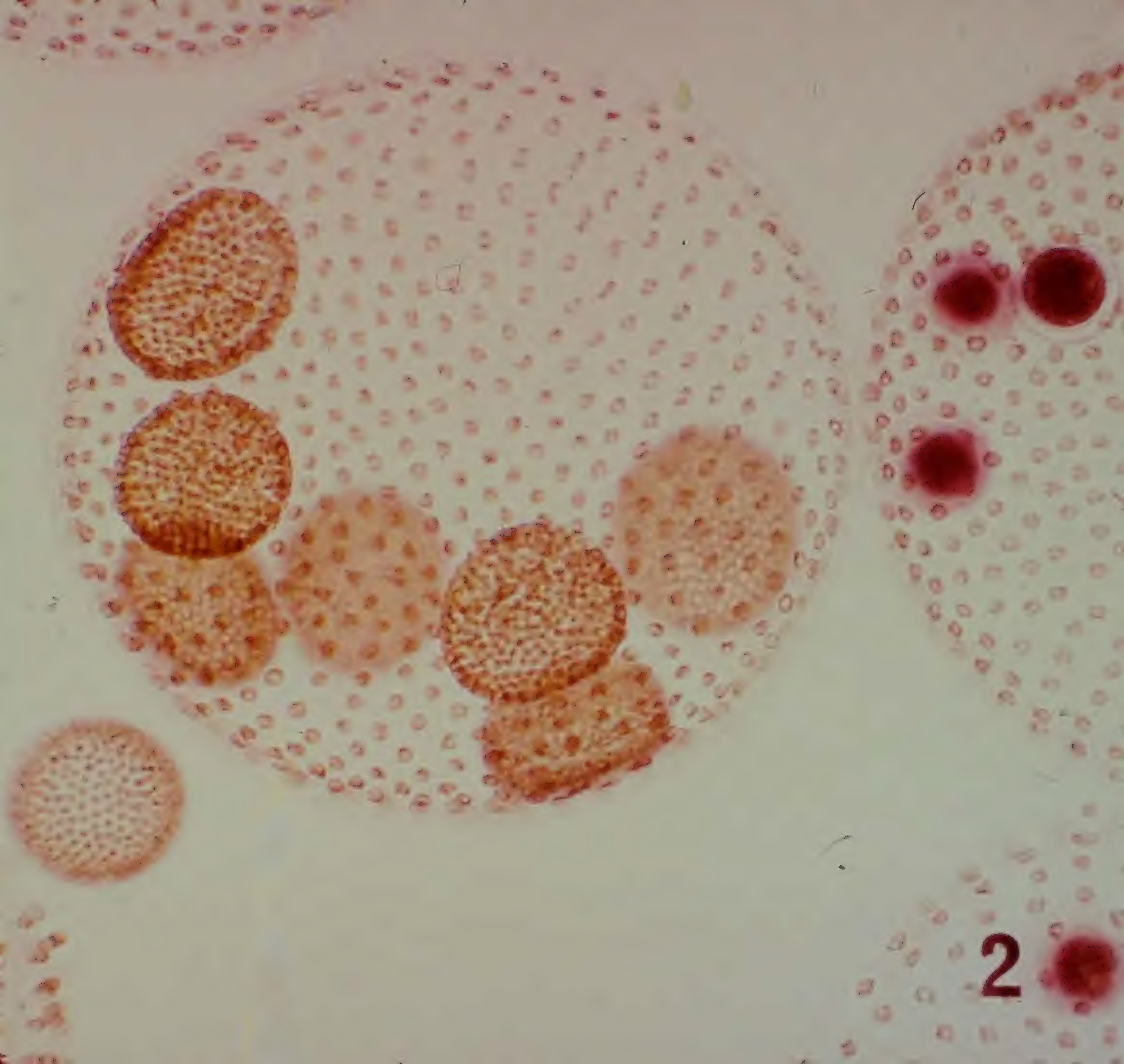
**Suggest a possible effect of blockage of the coronary artery or its branches.**

Any blockage of the coronary artery means that part of the cardiac musculature fails to receive its normal supply of blood. Deprived of oxygen and glucose, the muscle cannot continue to contract so the heart beat is impaired, sometimes with fatal results.

8 A stained section through a rat's heart showing the origin of the main blood vessel supplying the body (labelled A) from the left ventricle (labelled LV), magnified $\times 7.5$. Note the valves controlling the direction of blood flow (shown by the arrow). There is a comparable set of valves at the base of the pulmonary arteries that take blood from the right ventricle to the lungs.


18a

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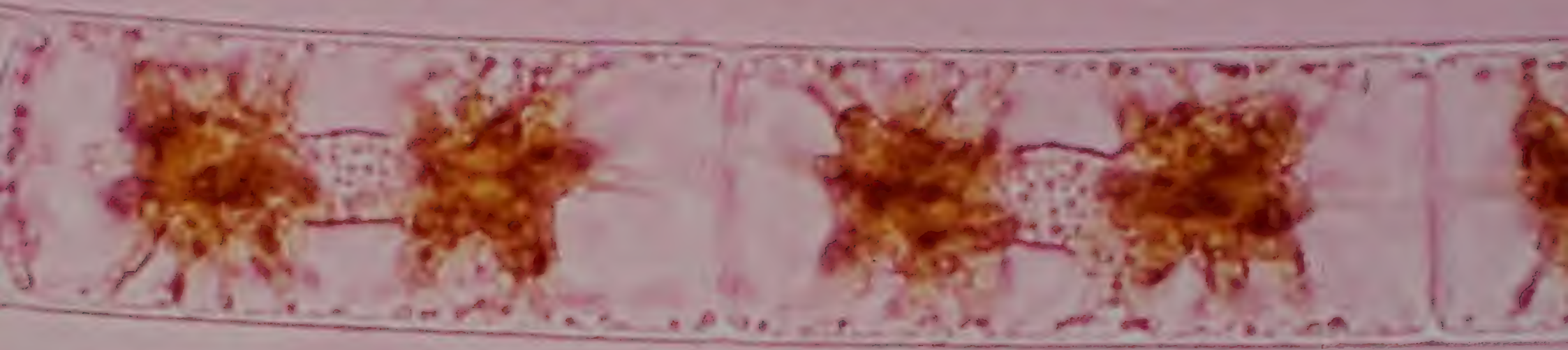

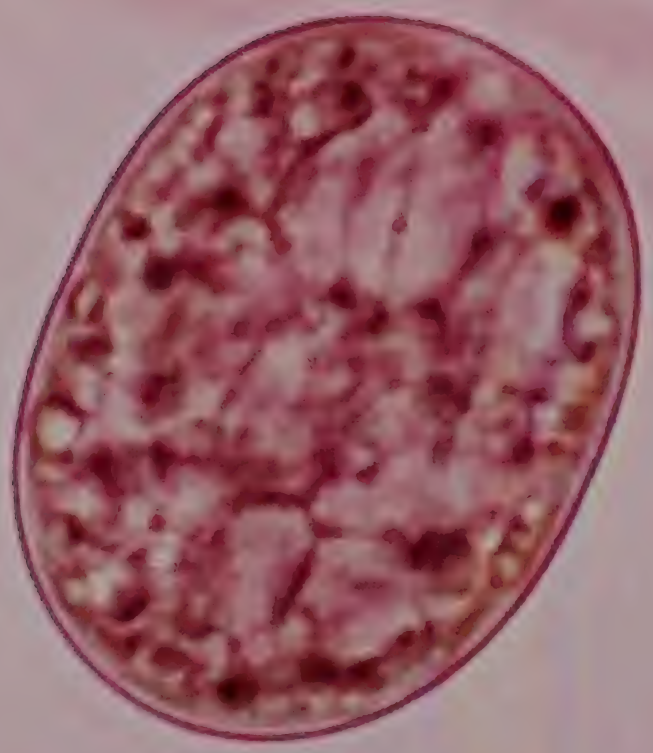

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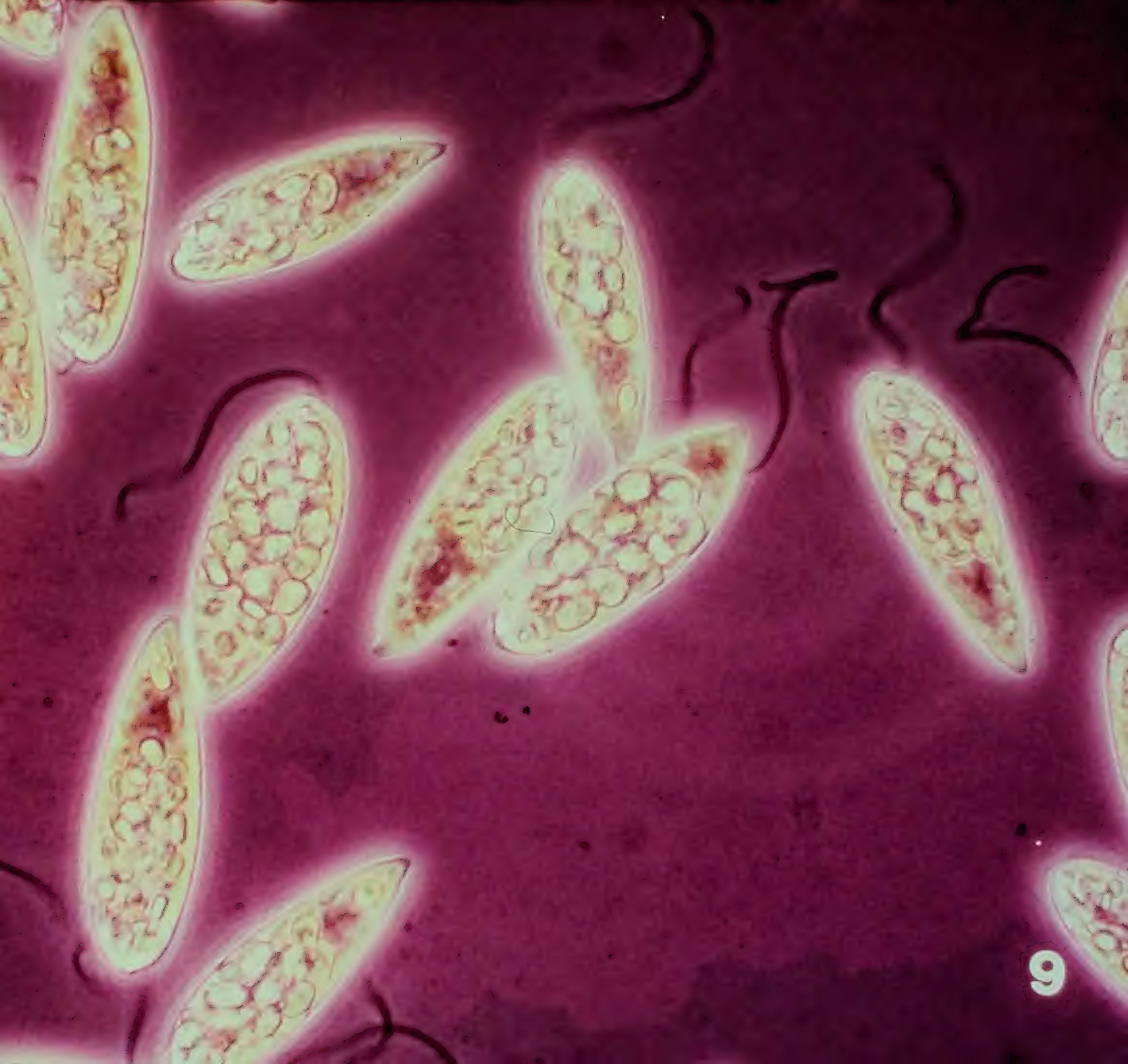

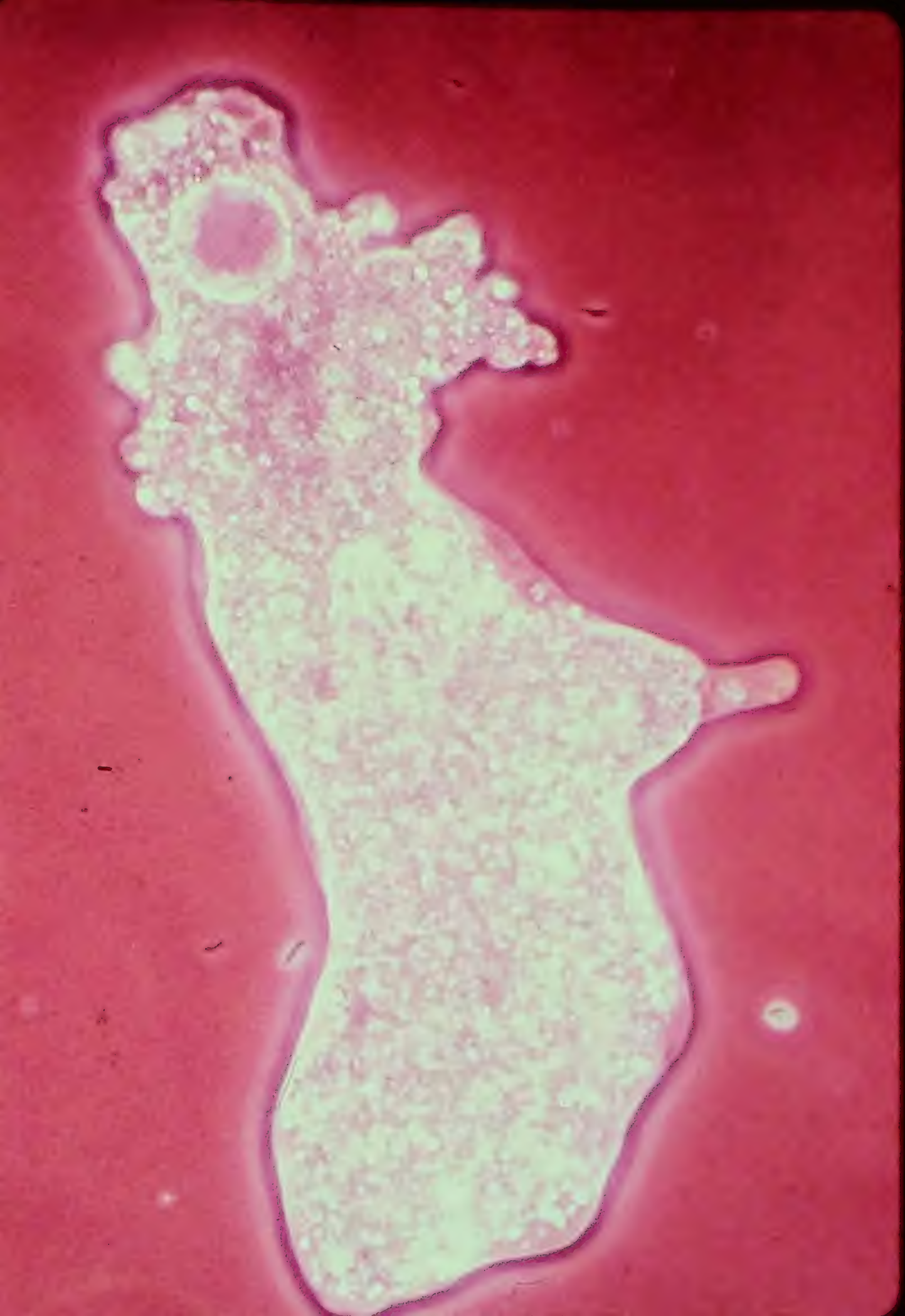

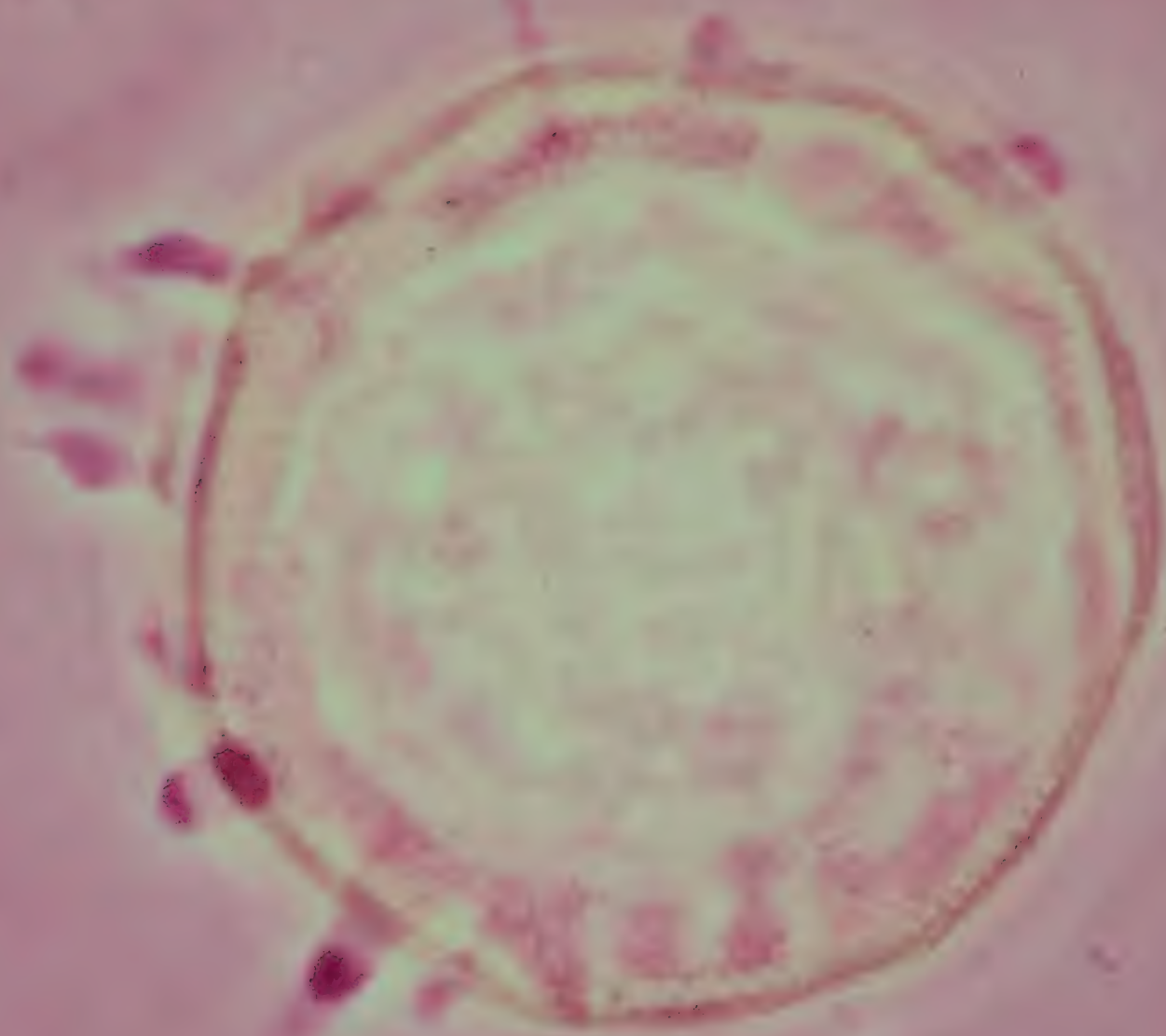

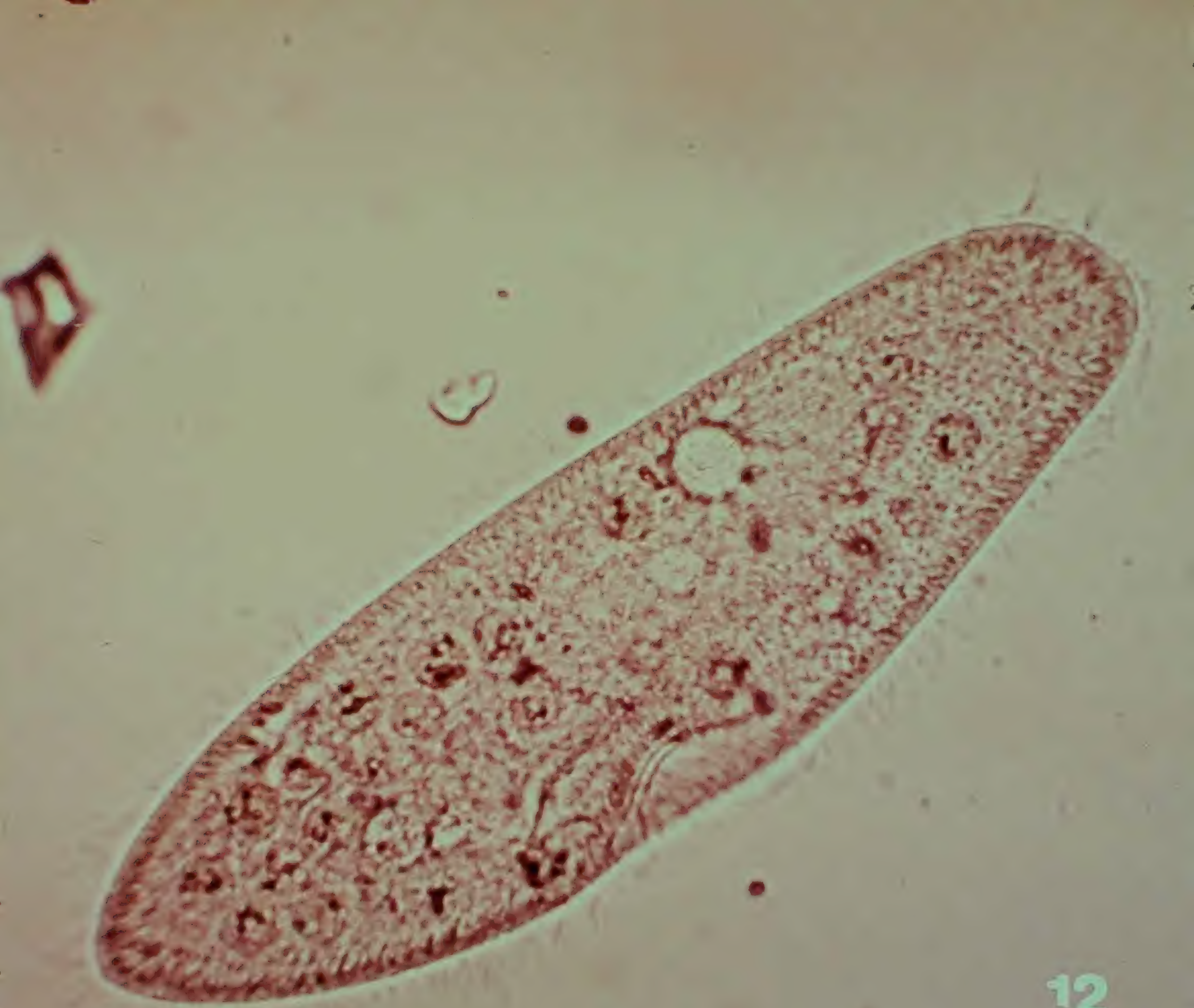

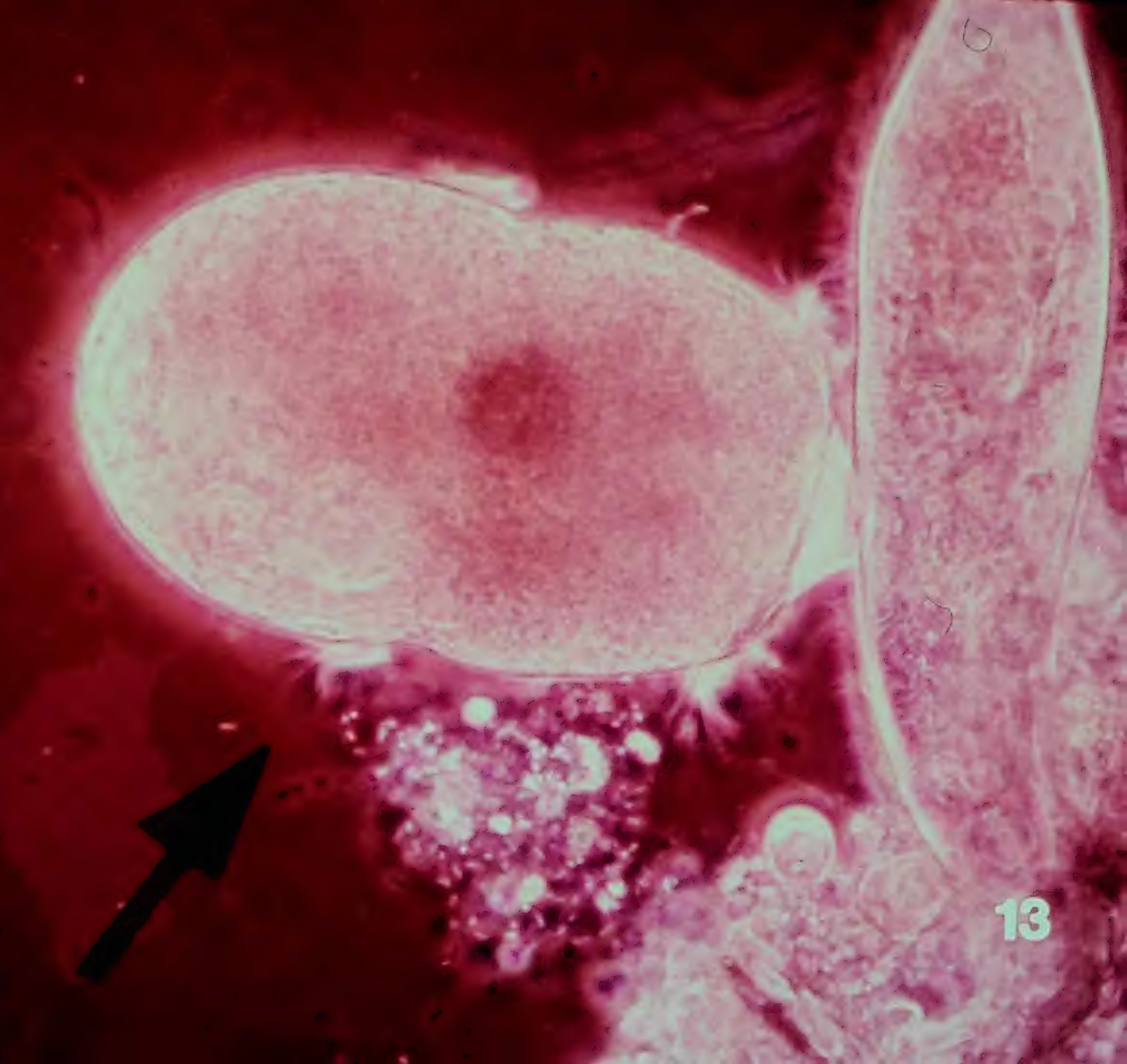

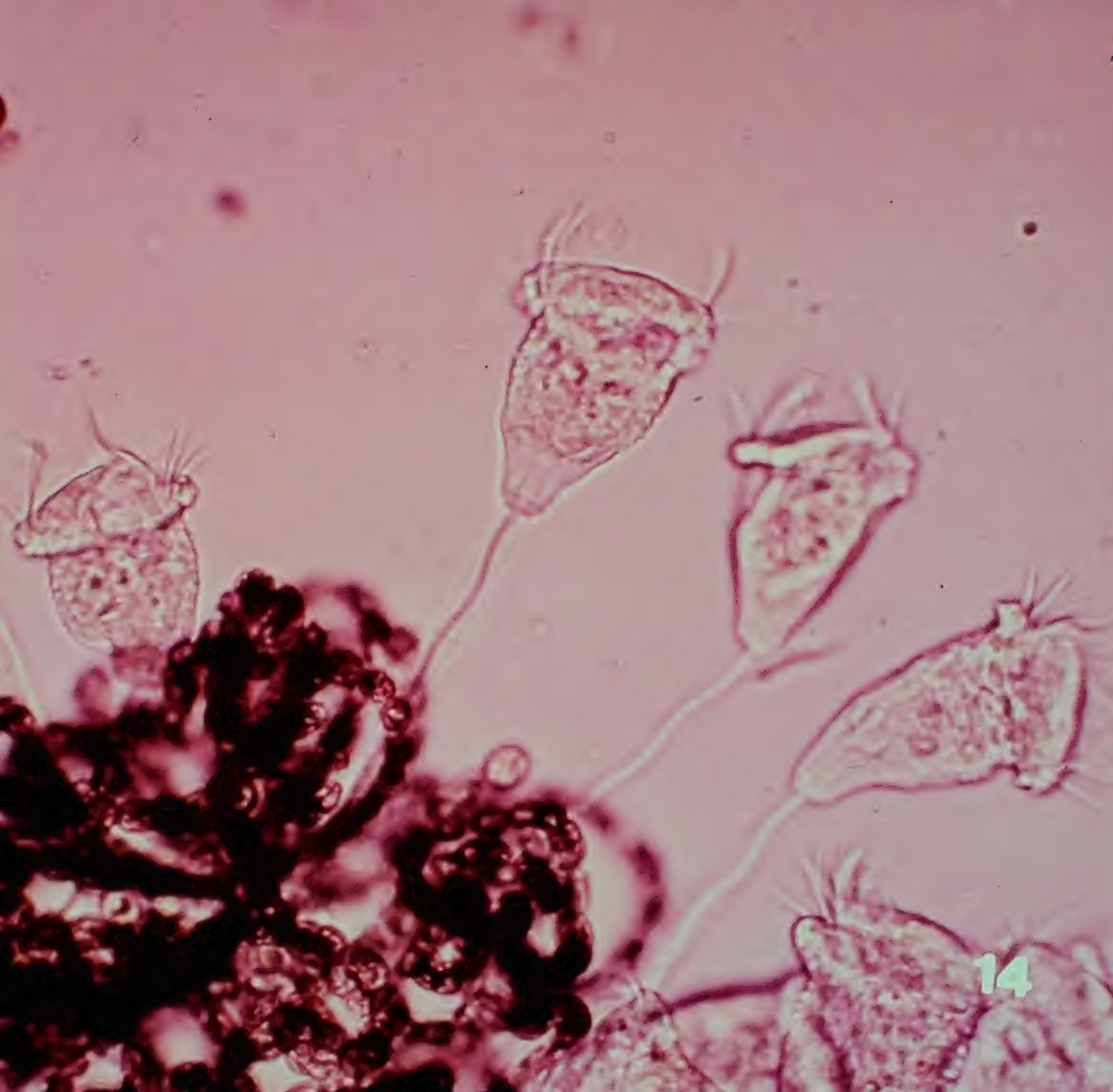

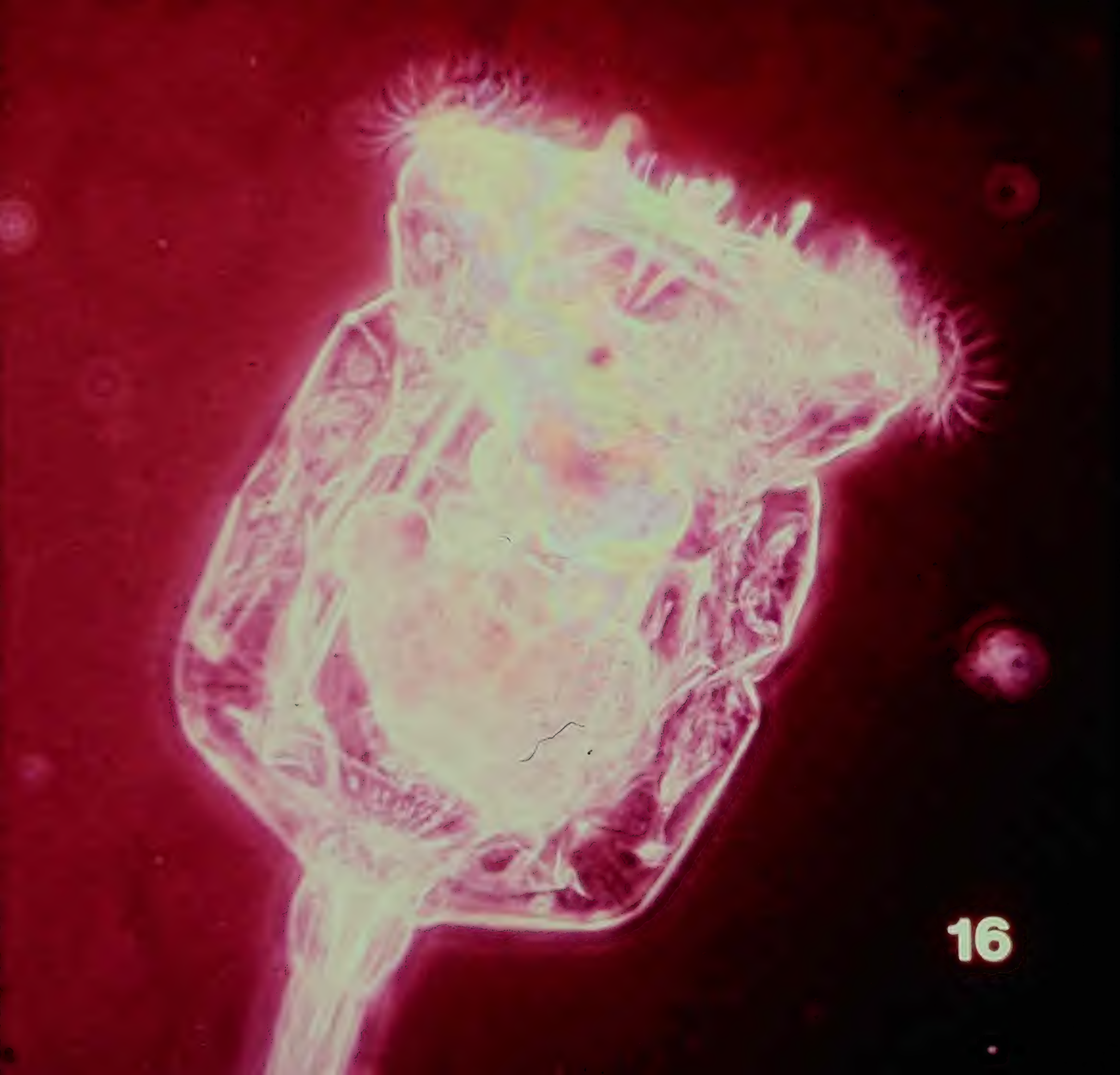

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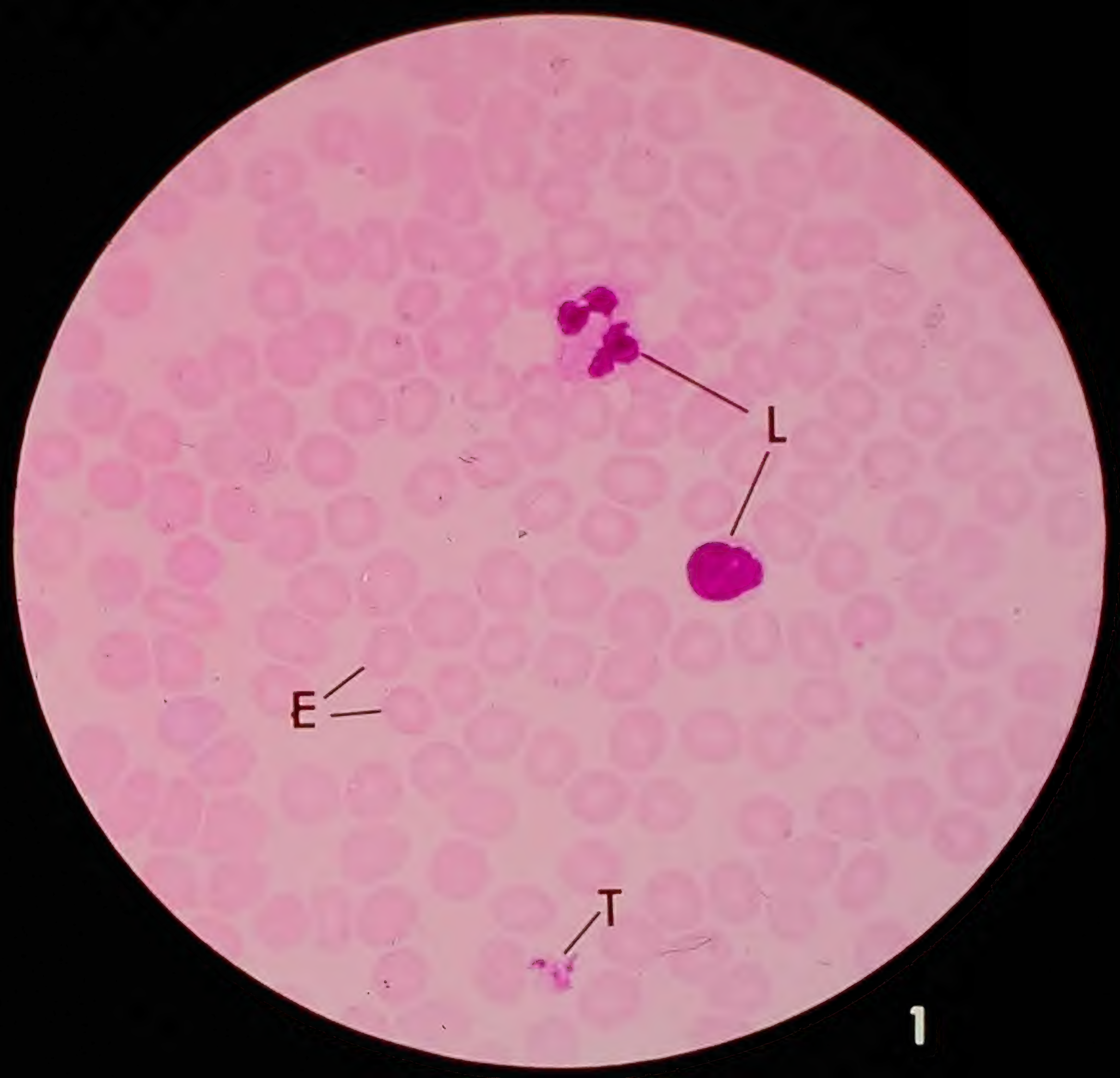


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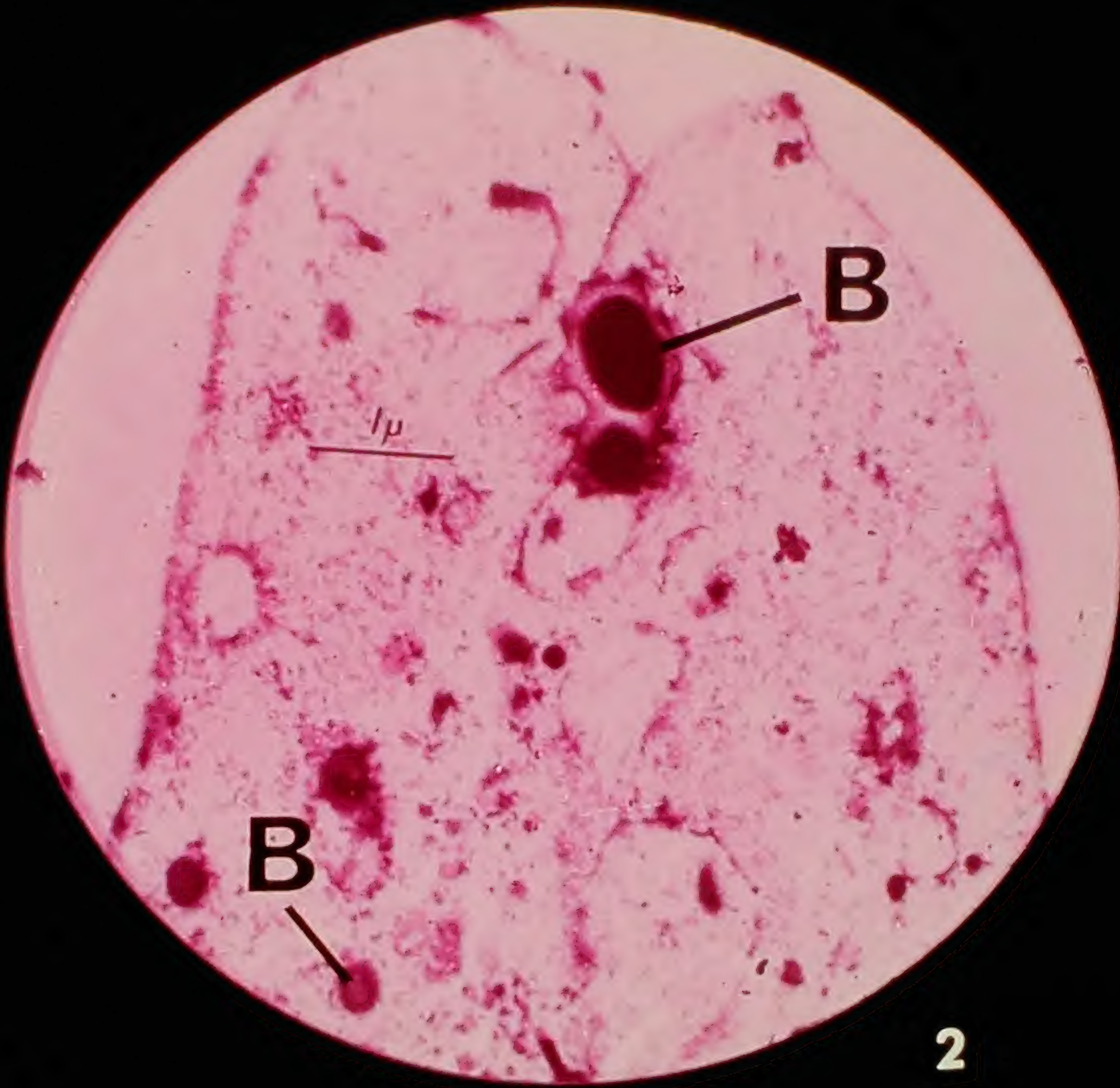
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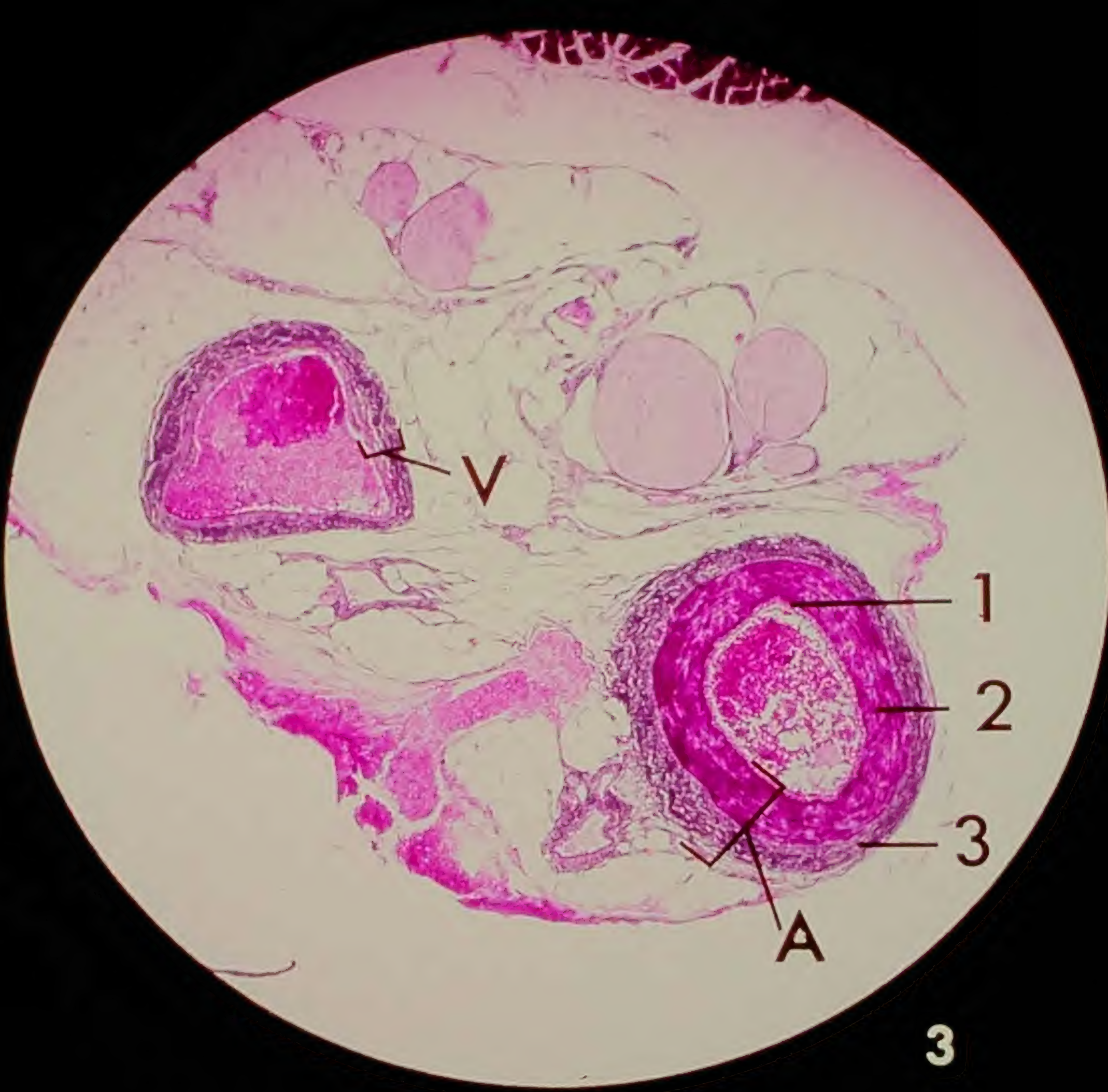


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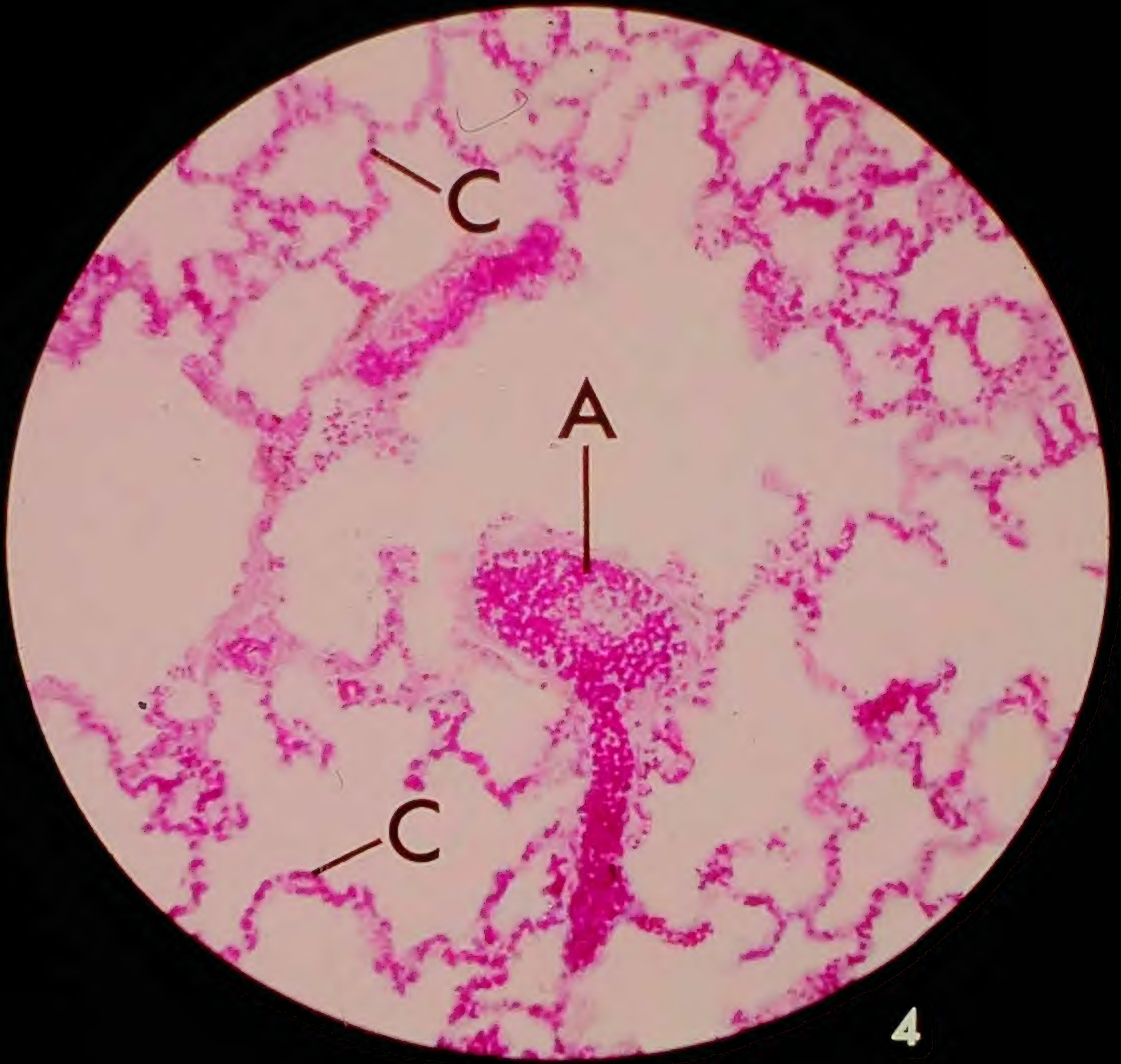
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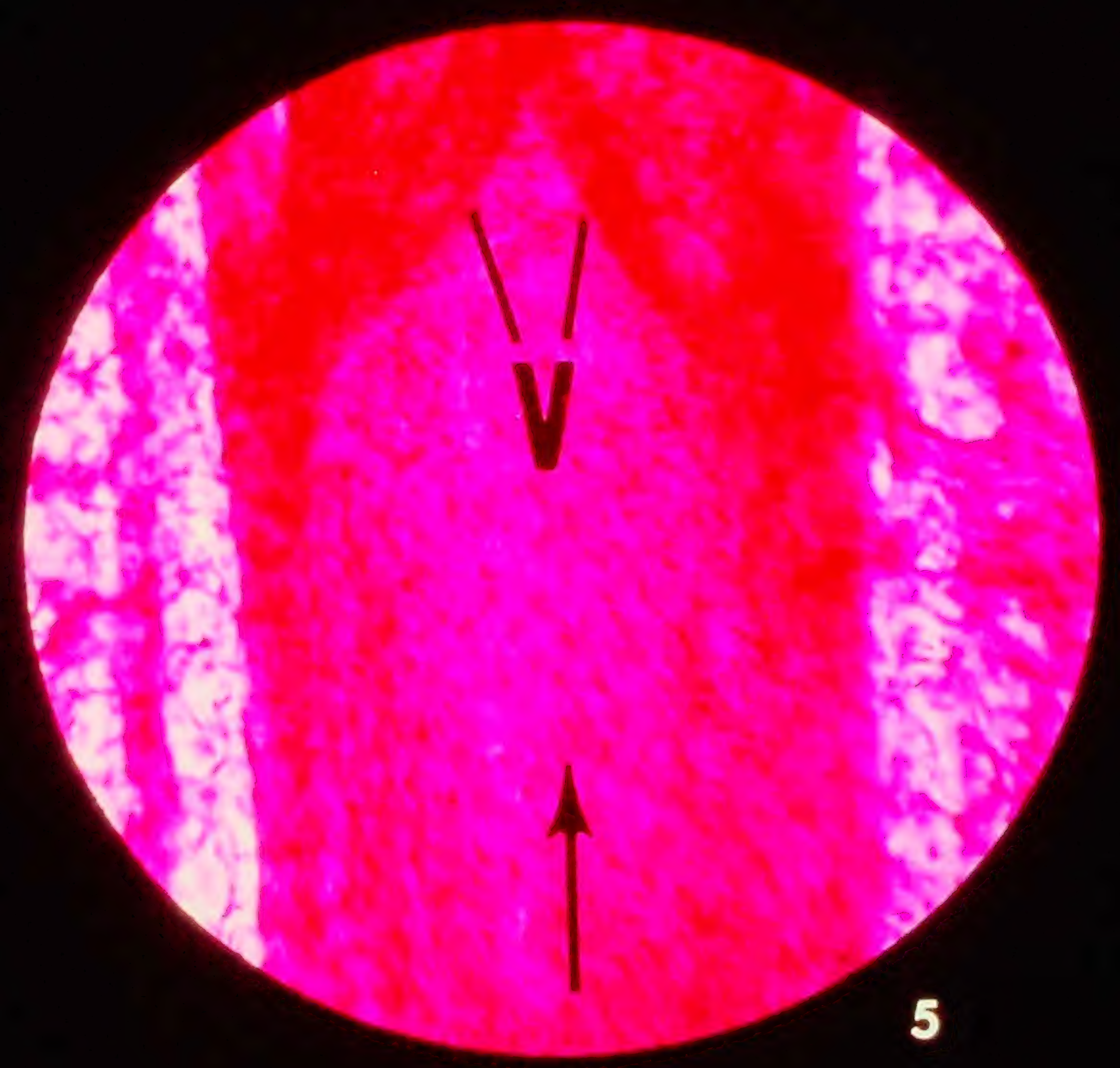

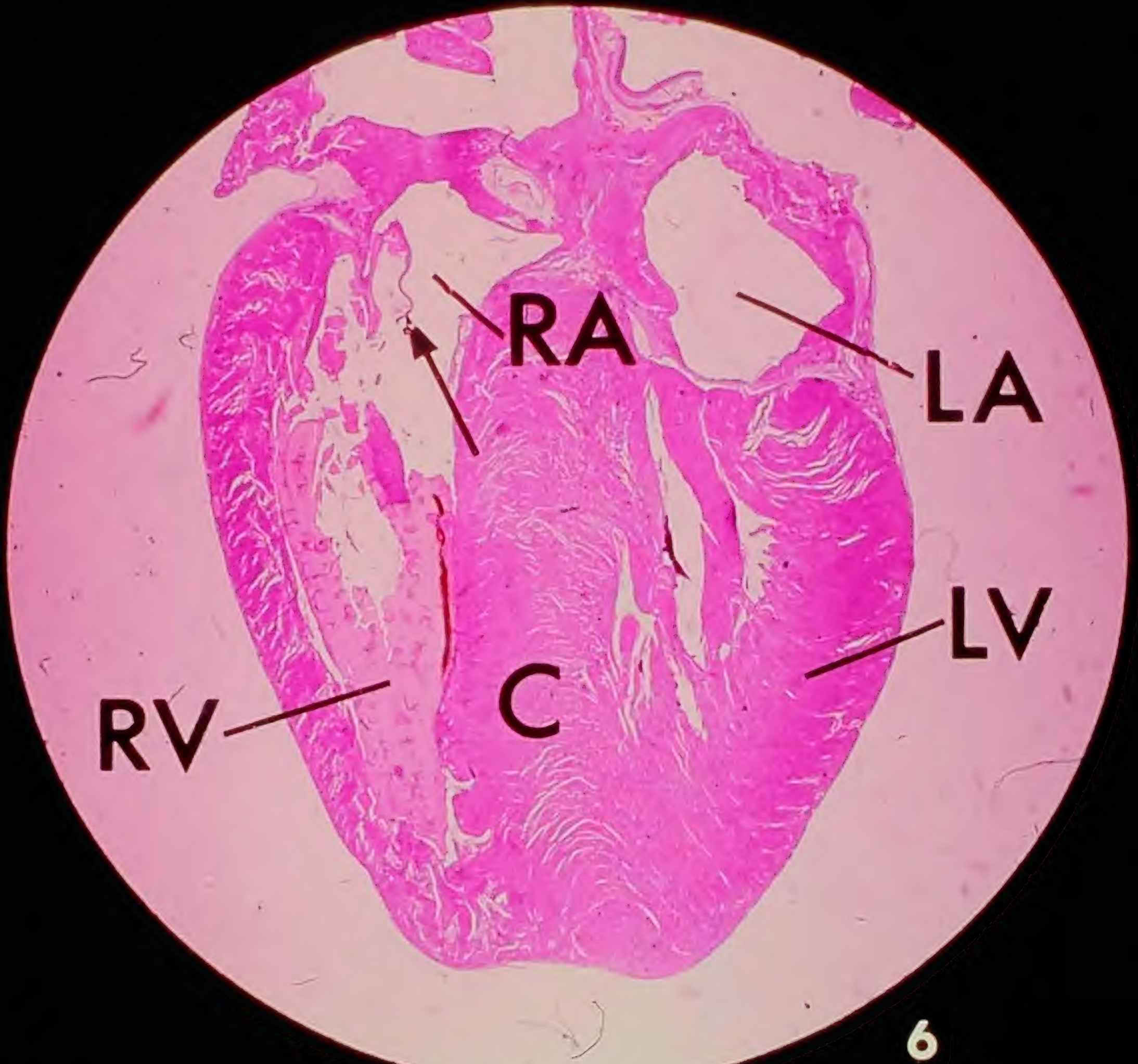
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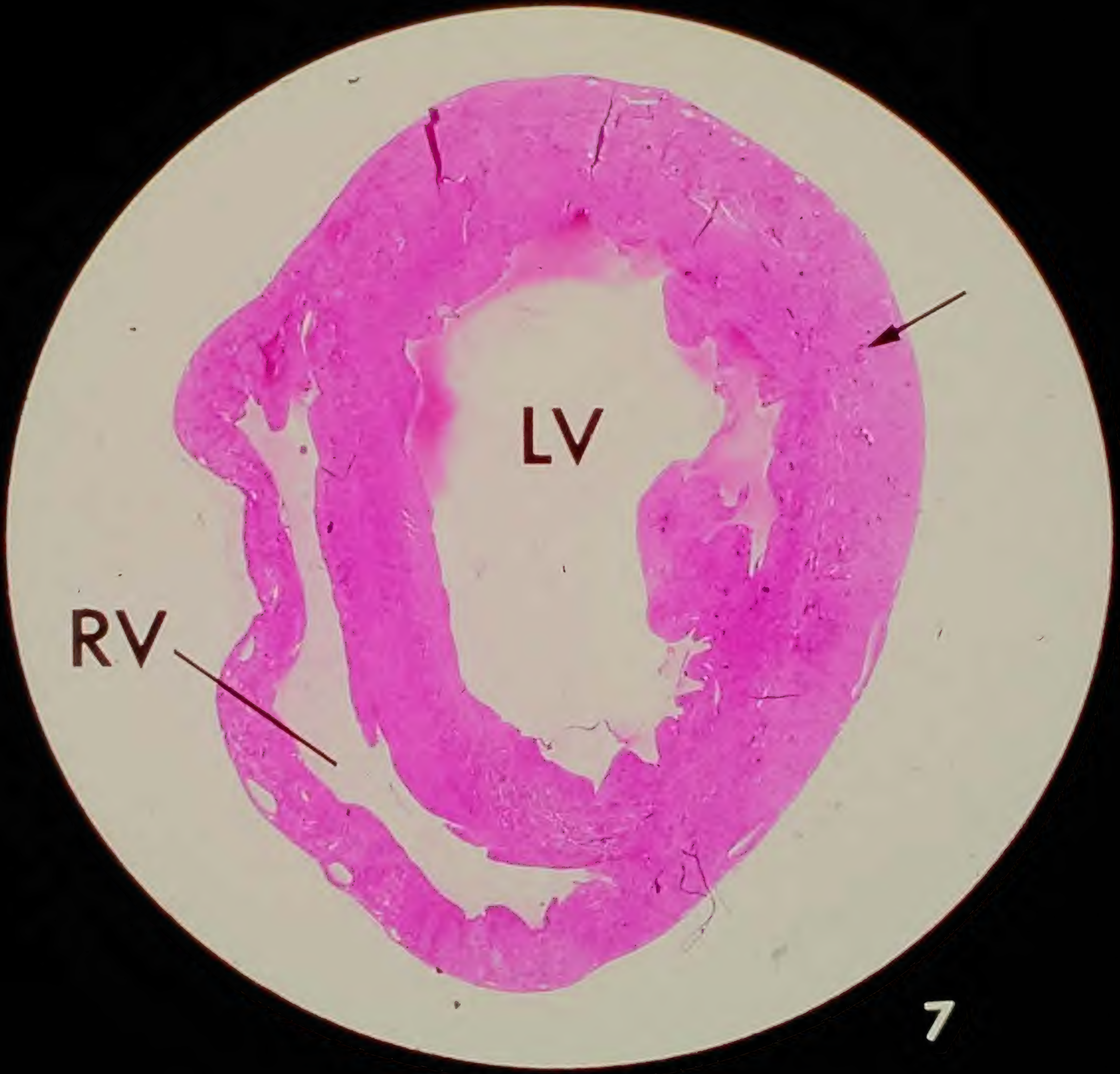
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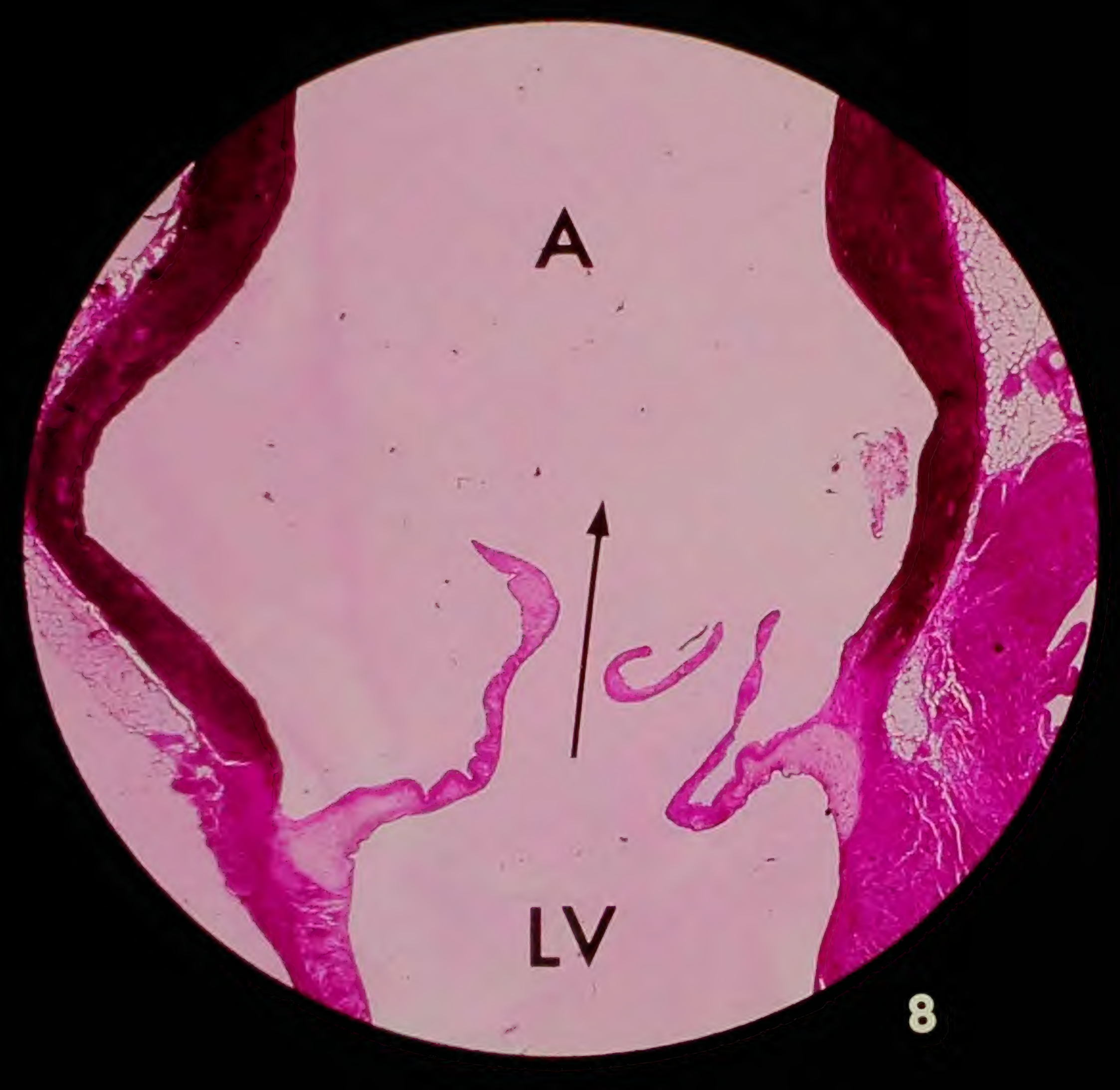
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# The Open University

**Notes**

S.100—SCIENCE FOUNDATION COURSE UNITS

1 Science: Its Origins, Scales and Limitations
2 Observation and Measurement

3 Mass, Length and Time
4 Forces, Fields and Energy

5 The States of Matter

6 Atoms, Elements and Isotopes: Atomic Structure
7 The Electronic Structure of Atoms

8 The Periodic Table and Chemical Bonding
9 Ions in Solution

10 Covalent Compounds

11, 12 Chemical Reactions

13 Giant Molecules

14 The Chemistry and Structure of the Cell

15, 16 Cell Dynamics and the Control of Cellular Activity

17 The Genetic Code: Growth and Replication
18 Cells and Organisms

19 Evolution by Natural Selection
20 Species and Populations

21 Unity and Diversity

22 The Earth: Its Shape, Internal Structure and Composition

23 The Earth's Magnetic Field

24 Major Features of the Earth's Surface
25 Continental Movement, Sea-floor Spreading and Plate Tectonics

26, 27 Earth History

28 Electromagnetic Radiation

29 Quantum Theory
30 Quantum Physics and the Atom

31 The Nucleus of the Atom
32 Elementary Particles

33, 34 Science and Society

## Instructions for Using the Film Strip Viewer

Arrange the home experiment kit viewer so that as much light as possible falls on the white reflector. Hold the film strip with the arrow to the left and the number right way up. Insert the numbered end of the film strip into the slot on the right side of the viewer and push it through. Look through the eyepiece with your eye close to it. Move the first picture into place and then adjust the focus by turning eye-piece. When you have examined the first picture, you can push the strip to the left to see the next one. The pictures are numbered at the lower right-hand corners. If necessary, clean the eyepiece and the surfaces of the film strips with a soft cloth or tissue.